Smart homes in transition - Investigating the role of households in the development of smart grids in Denmark

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SMART HOMES IN TRANSITION

Investigating the role of households in the development of smart grids in Denmark

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Preface

The work presented in this PhD thesis entitled *"Smart homes in transition – investigating the role of households in the development of smart grids in Denmark"* is part of the research alliance 'SusTrans: Enabling and governing transitions to a low carbon society'.

The focus of the PhD project has been to explore the role households have in a sustainable development of the energy system. The specific case for the PhD research project has been 'the smart grid', which implies a modernisation of the old 'analogue' electricity system with information and communication technologies to, among other things, ease the integration of intermittent energy sources like wind energy.

The PhD project was carried out by Sophie Nyborg at DTU Management Engineering at the Technical University of Denmark (DTU) and at the Center for Design, Innovation and Sustainable Transition (DIST) at the Department for Development & Planning, Aalborg University Copenhagen. The scholarship was co-financed by DTU, Aalborg University and the Danish Council for Strategic Research (the programme for Sustainable Energy and Environment).

The research project was conducted under the supervision of *Inge Røpke* (Professor (mso) from 1 August 2012) in the period June 2010 – January 2015, which includes 11 months of maternity leave, 13 months working part-time and 1 month working on a post doc project proposal. The PhD thesis also builds on research done for the iPower project during the last six months of this period. iPower is a strategic innovation platform where industries and universities meet to consolidate research and innovation activities in relation to the smart grid development.

This is a paper-based PhD thesis. The four papers that have been developed during my PhD research process are found at the end of this document. The overview presented in the first part of the thesis is intended to provide context, background and a final discussion of the four papers, as well as general reflections on my research journey, including the theoretical and empirical approaches I have grappled with.

The four papers could beneficially be read before or during the reading of the introduction to them and to the research process.

1. Nyborg, Sophie & Røpke, Inge (2011) *Energy impacts of the smart home – conflicting visions.* ECEEE 2011 Summer Study Proceedings: Energy Efficiency First: The Foundation of a low-carbon society, vol. 4, pp 1849 - 1860

   [Published as a peer-reviewed conference proceeding article]

2. Nyborg, Sophie & Røpke, Inge (2013) *Constructing users in the smart grid – insights from the Danish eFlex project.* Energy Efficiency, 6 (4), 655 – 670

   [Published as a peer-reviewed journal article]

3. Nyborg, Sophie (in progress/2015) *Lead Users and their families: Innovating flexible practices in the smart grid,* journal article manuscript

   [Submitted to S&TS Journal in April 2014. Review comments received in August 2014. Will be re-submitted to S&TS Journal after review comments have been incorporated]

4. Nyborg, Sophie & Røpke, Inge (in progress) *Heat pumps in Denmark – from ugly duckling to white swan*, journal article manuscript

   [The manuscript has not been submitted yet. An abstract for the paper was presented at the conference 'Smart Grids and the Social Sciences' in April 2014, and we have subsequently been invited to submit a full paper to a special issue of the peer-reviewed journal *Energy Research and Social Science*. Final decisions will be made based on the journal's ordinary peer review process. We are, however, still considering possible outlets for the paper].

This thesis has been submitted for assessment in partial fulfillment of the PhD degree. The thesis is based on the published scientific papers, submitted paper and paper manuscript, which are listed above. Parts of the papers are used directly or indirectly in the extended summary of the thesis. As part of the assessment, co-author statements have been made available to the assessment committee and are also available at the Faculty. The thesis is not in its present form acceptable for open publication but only in limited and closed circulation as copyright may not be ensured.

Acknowledgements

There are so many people I wish to thank for helping and supporting me throughout this research project that the first thing I have to acknowledge is that I cannot give you all the credit you deserve in this limited space. Moreover, I run the risk of forgetting someone. If I do, please forgive me – and thank you!

Nonetheless, I wish to start by thanking the people who have granted financial support to my project at the Danish Council for Strategic Research, at AAU and at DTU. During my research adventure, there are moreover a number of people I wish to thank for their intellectual, emotional, practical and personal support:

First, thank you to my supervisor, Inge Røpke, who has assiduously guided me through this process. Your door has always been open, both physically and intellectually. You have opened my eyes to a whole new world. Over the years, I have learned an incredible amount from being in your company. Thank you also to Peter Karnøe for being so optimistic and proficient during the writing of our project proposal. Thank you to Morten Elle for cheering for me, thank you to Hanne Lindegaard for our time together teaching, thank you to Christian Clausen for commenting on one of my papers and thank you to Susse Georg for being so cool. Chiara, Peter, Søren, Lea and Bente, sharing office space with you has been delightful. Eva Heiskanen, you have always managed to find the time to give me constructive feedback on my work. I don´t know how you do it, but thank you.

A big thanks goes to my 'fellow sufferers' (and please excuse me if the playful tone in the Danish expression does not translate well), the other PhD students as well as the other young researchers at our department and DIST as well as at DTU for making my life so much more fun while 'climbing the mountain' – and for insisting that Fridays need bubbles! Emil, Chiara, Rikke, Signe, Martin, Louise, Jens, Maj-Britt, Charlotte, Freja, Peter, Anders, Lars, Liv, Elisabeth, Signe, Joakim and Anne Katrine, you are wonderful, bright and inspiring people. A special thanks to you, Anne Katrine, for being such a good friend and for helping me with all kinds of things – such as with the design and layout of the thesis. Thank you to Ida, Trine and the secretariat for always helping me with practical stuff – and for doing sweet things such as putting cookies on our tables during Christmas.

I am grateful to DONG Energy, Poul Brath and antropologerne.com for letting me take part in their interesting project, and to all the people I have interviewed, who have taken the time to talk to me. A special thanks goes to Jørgen Gullev and H.C. Aagaard, who entrusted me with all their historical material. Jonathan Poole and Nicholas Haagensen, I will certainly recommend your proofreading services to my colleagues.

My friends and family truly deserve a word of thanks. My dear friends because I have been so absent in recent years, and yet you have not abandoned me. I have failed to tell you how much you mean to me, and I miss you all very much.

My family, who mean everything to me, and who have provided endless support, should also know how much I appreciate them. My big sister, Mathilde, my father, Otto, and my mother-in-law, Birthe, thank you so much for helping us with picking up the children from kindergarten and taking care of them when they were sick, for helping with the laundry, cleaning, cooking and so much more. I could truly not have done this research project without your help. My mother, Mette, and Kathinka, my twin sister, you have often been just as busy as I have, and yet you have also often managed to help us with the children and so many other things, also truly thank you to you. You are all fun, intelligent and excellent company, and you have loved me patiently, although at times I have certainly not deserved it!

Sweet Rosa and Vigga, thank you for being such kind, cool and loving stepchildren, and sweet Molly and Liv, I am endlessly grateful for having such marvellous little people as my daughters. I'm sorry for having been so absent at times, when there is nothing in the world I would rather do than spend time with you. Morten, my husband, thank you for understanding me so well and for your curiosity, humour and wit, and for everything in my life that is good. Thank you for our many discussions on what a sustainable future might encompass, for beings such an inspiration and for sharing my passion for this matter. I am so lucky to have you as my co-conspirator in life.

Abstract

Increasingly over the last decade, the 'smart grid' has been highlighted in many parts of the world as an important element in a low-carbon transition. The smart grid is a concept that entails the modernisation of the electricity system with information and communication technologies, in order to make the system more 'intelligent' and balance electricity production and consumption better. This new design is thought to address several current challenges to the electricity system, such as the increased integration of intermittent renewable energy sources due to climate change issues, peak demand and black-outs, fuel security, fraud and inaccurate billing.

The present PhD project aims to explore the role households play in a sustainable transition of the energy system and takes as its point of departure the Danish smart grid case. Here the smart grid is dominantly framed in relation to the political goal of basing the energy system 100 % on renewable energy, mainly wind power and biomass, by 2050. In a Danish context, households are expected to have a very specific role in the smart grid: the growing production of 'green' electricity, as more wind turbines are integrated in the system, requires that households also increasingly consume electricity through, among other things, the investment in heat pumps and electric cars, whereby they 'electrify' heating and transport. However, to utilise the intermittent wind energy production better and avoid escalating peak loads, households are expected to consume electricity more 'flexibly', with the aid of smart home energy management technologies and motivated by new pricing structures. This means they should, for instance, have their heat pump turned off during peak hours or turn on their washing machine 'when the wind blows'.

Through qualitative fieldwork in the Danish smart grid case and participatory observation in the eFlex project – a user oriented smart grid innovation project commissioned by the energy group 'DONG Energy' involving 119 Danish households – the PhD project explores this techno-economically-driven vision for a sustainable transition of the energy system. By drawing on science and technology Studies (STS) and practice theory, the thesis investigates critically the vision of 'the smart-home-in-the-smart-grid' and points out possible unsustainable development paths that may result from this vision. The thesis also investigates critically the role energy system actors play in constructing consumer images that 'fit' with the system that is being built.

Furthermore it is argued that the pervasive framing of the householders' relationship to energy solely in terms of their role as consumers of it is insufficient in terms of understanding the dynamics of everyday life and how it changes. Ethnographic fieldwork in 'eFlex households' demonstrates firstly how householders can also have more active and innovative roles in the system and, secondly, how smart technologies interact with the continuous changes of domestic practices. The thesis also calls for a break with the 'smart grid roll-out' terminology by unfolding a historical case study of the development of heat pumps in the Danish energy system. Thus, it is argued that the present low carbon transition of the energy system is still a contested issue, and that many development paths besides the 'smart grid path' can emerge in which households will and should play a vital role beyond making the 'right consumer choices'. Finally, a discussion of the policy initiatives that can support a more sustainable societal development and configuration of the energy system is presented.

Resumé

Gennem det seneste årti er det 'intelligente elnet' eller 'smart grid' i stigende grad blevet fremhævet mange steder i verden som et vigtig element i omstillingen mod et samfund, der bruger mindre fossil energi. Dette smart grid indebærer en modernisering af elsystemet med informations- og kommunikationsteknologier, så systemet bliver mere 'intelligent' og bedre i stand til at balancere produktion og forbrug af el. Det er meningen, at det nye design skal takle flere nuværende udfordringer, som elsystemet står over for såsom den øgede integration af vedvarende energikilder på grund af klimaforandringer, spidsbelastninger i nettet og strømafbrydelser, forsyningssikkerhed, svindel og unøjagtige afregningsmetoder.

Det foreliggende Ph.d. projekt har til hensigt at undersøge den rolle, som husholdninger har i en bæredygtig omstilling af energisystemet og tager udgangspunkt i den danske 'smart grid case'. Her er 'the smart grid' hovedsageligt forstået i forhold til det politiske mål om at basere energisystemet 100 % på vedvarende energi, hovedsageligt vindenergi og biomasse, inden 2050. I en dansk kontekst forventes husholdningerne at spille en meget specifik rolle i 'the smart grid': den øgede produktion af 'grøn' el efterhånden som flere vindmøller integreres i systemet kræver, at husholdningerne også forbruger mere el og blandt andet investerer i varmepumper og elbiler, hvorved de elektrificerer varme og transport. For at udnytte den fluktuerende vindenergi bedre og undgå spidsbelastninger i nettet, så forventes husholdningerne dog også at bruge el mere 'fleksibelt' med hjælp fra intelligente energistyringsteknologier og motiveret af nye prisstrukturer. Dette betyder, at de f.eks. skal have deres varmepumpe slukket i perioder med spidsbelastning eller tænde for vaskemaskinen, når 'vinden blæser'.

Gennem kvalitativt feltarbejde i det danske smart grid felt og deltagerobservation i eFlex projektet – et brugerorienteret innovationsprojekt DONG Energy gennemførte med 119 husholdninger – har Ph.d. projektet udforsket denne tekno-økonomisk drevne vision for en bæredygtig omstilling af energisystemet. Ved at trække på videnskabs- og teknologistudier (STS) og praksisteori undersøger afhandlingen kritisk visionen for 'the-smart-home-in-the-smart-grid' og peger på de mulige ubæredygtige udviklingsveje, denne vision kan føre til. Afhandlingen udforsker også den rolle, som energisystemaktører spiller i konstruktionen af brugerportrætter, der passer til det system, de gerne vil udvikle.

Derudover kritiserer afhandlingen den meget udbredte forståelse af husholdningers forhold til energi, hvorigennem de udelukkende bliver set som værende forbrugere af det og argumenterer for, at dette perspektiv er utilstrækkeligt til at forstå hverdagslivets dynamikker og hvordan det ændrer sig. Etnografisk feltarbejde i 'eFlex husholdninger' demonstrerer for det første, hvordan husholdninger også kan have mere aktive og innovative roller i systemet og for det andet, hvordan teknologier og husholdningspraksisser indvirker på hinanden. Afhandlingen opfordrer også til et brud med 'smart grid udrulning' terminologien gennem et historisk casestudie af udviklingen af varmepumper i Danmark. På den måde argumenterer afhandlingen for, at den nuværende omstilling af energisystemet stadig er et kontroversielt emne og at mange omstillingsveje udover 'smart grid vejen' kan fremkomme, i hvilke husholdninger vil og bør få en vital rolle, der går ud over at tage de rette 'forbrugervalg'. Til sidst diskuteres hvilke politiske initiativer der kan tages for at understøtte en mere bæredygtig udvikling af samfundet og -konfiguration af energisystemet.

Contents

1 Introduction

The economic historian Joel Mokyr describes new technologies as 'hopeful monstrosities' – "hopeful because product champions believe in a promising future, but monstrous because they perform crudely" (Schot & Geels, 2008: 537). Without necessarily adopting Mokyr's understanding and use of the expression, these two words certainly fit the smart grid in many ways.

In the last 5 - 10 years, the smart grid has on a global scale increasingly been hyped as one of the most important elements in a sustainable transition of the energy system, and great hope is attached to this prospective revolution of the electricity grid. Indeed, "smart stuff has captured the imaginations of governments and industries around the world" (Strengers, 2013: 1) who believe that augmenting the electricity grid and households with information and communication technologies will solve a range of current issues facing energy system transition. Meanwhile, the smart grid is also still 'performing crudely': arguably, the smart grid is certainly a performative and powerful vision that aligns actors and attracts huge funding for research as well as political support (Lunde et al., in progress). On the other hand, it is, as of yet, mostly 'just' a vision, which is barely performing at all in the sense that it is still an ambiguous concept with which we in reality have little 'real life' experience. More importantly, however, so far interest from policy makers and industry has mainly been focused on developing smart grid technologies and on analysing the economic potential, whereas ideas about how this intelligent electricity grid is actually going to take hold in society and how it will interact with the everyday life of the 'users' of it are quite absent. Instead, when the role of households *is* actually taken into account, the knowledge interests are very narrowly focused on exploring consumer incentives to unravel how householders as consumers can be motivated to play their part in the smart grid vision (Gangale et al., 2013; Strengers, 2013; Verbong et al., 2013). Accordingly, the vast majority of research projects involving 'the human factor' thus employ quantitative methods to survey individuals' response to price signals or to detailed information on energy consumption, or they employ other market research methods to segment consumers, so they can be appropriately targeted. This approach is fundamentally based in an idea that households are populated by *Resource Man* (Strengers, 2013: 2), i.e. the rational, data-hungry and tech-savvy new energy consumer, who responds to incentives such as price signals and whose behaviour is mediated and enabled by smart data and technology – it is through the new smart grid technologies that he (!) *becomes* smart. As the work in this thesis will hopefully demonstrate, designing a system purely in this image and neglecting or overlooking the multitude of ways households have a role in energy system development misses part of the picture and may result in a system that is crudely performing 'out in the real world'. This could in fact have 'monstrous' effects on energy consumption quite contrary to the high sustainability hopes for it.

That the work in this thesis is an important contribution to the emerging debate concerning smart grids in the social sciences is also emphasised by the sociologist Yolande Strengers, whose recent book 'Smart Energy Technologies in Everyday Life. Smart Utopia?' (Strengers, 2013) represents one of the newest and most comprehensive reviews and discussions on the subject. Strengers argues that, "given the scale and scope of change intended for smart energy technologies and their consumers, the lack of interrogation of this vision is alarming" (Strengers, 2013: 3). Although some researchers – besides Strengers – have started taking on such an interrogation, and important work has been done to provide alternatives to the individualistic and techno-economic focus in the smart grid field (e.g. Christensen et al., 2013; Hargreaves et al., 2010; Hargreaves, Nye et al., 2013; Hargreaves & Wilson, 2013; Heiskanen & Matschoss, 2012; Marres, 2012; Powells et al., 2014; Schick & Winthereik, 2013; Strengers et al., 2014; Walker, 2014) and in the field of domestic energy consumption and sustainability issues in general (e.g. Aune, 2007; Berker, 2013; Gram-Hanssen, 2011; Jalas & Rinkinen, 2013; Palm & Darby, 2014; Shove et al., 2012; Shove & Walker, 2014; Wallenborn & Wilhite, 2014) the subject has by no means been exhausted. To quote Strengers again, "indeed the lack of empirical qualitative research on this subject is a critical gap in need of further attention" (Strengers, 2013: 69). Yolande Strengers and I have worked in parallel with addressing this gap, as I had not read her recent book during my research process and when I wrote my papers. However, reading her book before contemplating this final introduction to my papers has provided excellent food for thought when putting my work into perspective.

Undeniably, the current dominant and rather narrow approach to 'managing the dissemination of smart grid technologies' is rooted in a long-standing 'disciplinary preoccupation' in policy making with changing individuals' attitudes, behaviour and choices (Shove, 2010) to enhance energy savings or generally support a sustainable development in some way or other. Thus, much contemporary policy focuses on the responsibility of the individual to 'make the right choice'; this is often considered to be driven by economic rationality, which represents "a strikingly limited understanding of the social world and how it changes" (Shove, 2010: 1273).

Such ideas about the individuals' role in societal change are often paralleled by understandings about the 'dissemination' of technologies in society, which could equally benefit from a more socio-technical perspective. Often the word 'roll-out' is used in relation to smart grid technologies. Such terminology represents a fundamental idea that these technologies can unproblematically 'sweep out into the world' "in an orderly and efficient manner" and substitute existing 'dumb' technologies so they "are able to do their work" (Strengers, 2013: 24). However, the 'roll-out' of smart grid technologies is co-developing with a range of factors such as already established and path-dependent structures and domestic practices as well as power struggles between actor groups over, for instance, getting to define the meaning and value of the technologies. Moreover, as Strengers argues, such ideas of technology as being "detached, disinterested and unquestionably loyal servants… resonate with the 'techno-economic optimism' central to capitalist societies, where eco-efficiency is promoted as a way of curtailing the impacts of the growth paradigm, but at the same time subtly reinforces it" (2013: 24). Thus, the smart grid is not a 'neutral technology', but indeed a political phenomenon, which can for instance also be seen as part of a broader political ideology of assigning responsibility for combatting climate change to the individual and his or her consumer choices. As we mention in paper 3, the liberalisation of the energy markets is part of the smart grid interest and engagement in Denmark. Accordingly, smart home energy technologies are related to an ideology "where market systems are delegated the task of regulation previously managed by states" (Strengers, 2013: 24). Besides promoting 'the right choices', the smart meter and smart displays are therefore also intended to support householders' participation in energy markets.

Hence, there are still many things to explore in relation to smart grids and households, and certainly other disciplinary approaches to do it with than the 'disciplinary preoccupations' mentioned by Shove above. These disciplines – social psychology, behavioural economics and rational choice theory, informational-deficit models etc. and the belief in linear technological transfer and substitution – are all very prominent ideas in the smart grid imagery (Strengers, 2013: 4). Instead, other literatures and ontologies have been brought into play in this research process, which I believe have helped me to provide a more colourful and "richer and more nuanced understanding of the world" (Nicolini, 2012: 215). My theoretical approaches probably also bear witness to the fact that I have been situated among scholars working with user-oriented design and innovation as well as with sustainable transition theories. I have gained interesting insights from practice theory and socio-material ontologies (Berker et al., 2006; Geels, 2002; Latour, 1992; Oudshoorn & Pinch, 2003; Reckwitz, 2002; Shove et al., 2012), which have fertilised my thinking about the subject in ways that have provided, I believe, a little more complexity to our understanding of households and their role in current energy system transformations.

What has been neglected and still needs exploration is thus a broader set of interests in relation to the role households have in 'materialising the smart grid phenomenon' – or not. These households are consistently narrowly framed as 'the consumer or demand side' and as the new energy consumer is "cast in the male-dominated industries of engineering, economics and computer science" (Strengers, 2013: 2), a strikingly uniform image of him has taken hold. This calls for research that opens up households to demonstrate that these not only consist of Resource Man, but also his family, as well as contested versions of him and even pets, plants, differing meaning ascriptions etc. Moreover, a useful addition to the dominant conceptualisation of energy as 'a resource', 'commodity' or 'impact' (Strengers, 2013: 44) is to consider energy as completely entangled in most of our everyday, 'non-smart' activities and practices (Strengers, 2013: 3), which provides a richer picture of how technologies are integrated into everyday life and change as a result of this interaction.

However, what was even more pertinent when this research process was started 4 years ago was firstly a critical discussion of the whole premise for articulating householders in this role and thus discussing what actually constitutes this pervasive, powerful and 'techno-economic optimistic' vision? For instance, is the smart grid vision in its dominant form at all sustainable, or is it possibly "maintaining and enhancing current lifestyle expectations" (Strengers, 2013: 23) and "realising an ICT-enabled and electricity-dependent smart lifestyle featuring unprecedented levels of luxury and 'pleasance'?" (2013: 11). As Strengers says, "an explosion of international research has evaluated and predicted the costs and benefits of smart metering and smart grids, and outlined in significant detail the anticipated role of and for the new energy consumer; but what of the vision itself? What are the assumptions, histories, politics and predictions embedded in the smart utopia? …What realities is this vision performing?" (2013: 8). Finally, what has not been explored sufficiently according to Strengers is the role that energy system actors have in creating consumers that fit into the system and how they "manufacture consumers ontologically" (2013: 29). Consumer research projects that naturalise and reproduce certain roles for the householders are "incredibly important because consumer conceptualisations are productive, not only representing and understanding consumers, but also producing and creating them" (2013: 35).

Some of the above-mentioned issues and 'gaps' in knowledge are what I have been concerned with during this research process. Whereas the first paper explores the vision of the smart home in the smart grid and points to possible unsustainable directions that may result from this vision – and the 'funwashing' of boring energy management technologies we argue it entails – the second paper critically investigates the role that energy system actors have in constructing strategic user images. The third paper opens up households to move beyond the pervasive framing of householders' relationship with energy solely in terms of their role as consumers of it (Strengers, 2013: 40). The paper more specifically explores how householders can have many other roles in relation to the system and how the domestication of smart energy technologies interacts with a range of everyday practices, which has great importance for the development of smart home technologies and for the 'innovative processes' in the home. Finally, paper four breaks with the 'roll-out' terminology by unfolding a historical case study of heat pumps in Denmark and the Danish energy system, which clearly demonstrates that the dissemination of technologies is not due to an inherent technological supremacy or a result of consumers' 'willingness' to make the right consumer choices. Rather, technologies are indeed 'political tools' that are infused with power-relations and householders are not necessarily willing to enrol in the 'programs of action' and visions laid out for them. Creative and innovative individuals and their reproduction and development of social practices have had an important part to play in the development of the Danish energy system – and as this thesis will exemplify, households still take an active and 'creative' role in their own energy supply.

Thus, the following research questions have been addressed in this research process:

1. *What role are households envisioned to have in the smart grid? What constitutes this role and how do energy system actors explore and strategically construct this role? (Papers 1 and 2)*
2. *What roles do households have in the energy system, other than being merely 'consumers'? (Papers 3 and 4)*
3. *How do families domesticate smart home energy management technologies and how do the technologies interact with the continuous changes of domestic practices? (Papers 2 and 3)*
4. *How do historical conditions and past and current controversies shape the present development and configuration of the smart grid? How can policies contribute to a sustainable configuration of the smart grid? (Papers 1 and 4)*

However, although the papers perhaps seem like the result of a linear, logical and uncomplicated 'route from a to b', it goes without saying in an STS research community that this is of course far from what actually happened. Several plans were replaced by 'situated action' (Suchman, 1987), and my journey has been troubled by detours and dead-ends. However, I have learned something all the way.

Before sharing my research process, I will elaborate a little bit more on what the smart grid vision entails and how it is situated in a Danish energy policy context.

2 The smart grid vision and the flexible consumer

In general terms, the smart grid vision implies making the electricity grid more ‘intelligent’ by applying information and communication technologies to the electricity grid. The main challenge is to balance consumption and production in the grid and the basic architecture should thus consist of a ‘power exchange highway’ and a ‘data exchange highway’, which improves the monitoring and control of the system’s performance and enables the necessary real-time dynamic feedback and interaction between households and the energy supply system. Such a design is thought to increase the reliability, efficiency, security, economy and sustainability of the electricity grid by addressing several current challenges to the electricity system, such as peak demand and black-outs, the increased integration of intermittent energy sources due to climate change issues, fuel security, fraud and inaccurate billing (Darby, 2010). Interpretive flexibility in relation to the smart grid is still great, and the more specific expectations of the smart grid vary greatly among stakeholders. Thus, *what the smart grid is* obviously depends on the specific socio-technical and institutional setting (e.g. national context) the vision is born in and with which the grid is imagined to interact.

In a Danish context, the smart grid is clearly framed by energy system actors in relation to the last and the current governments’ political goal that the Danish energy system can be based 100 per cent on renewable energy by 2050 (Regeringen, 2011). As a consequence of the energy agreement with the opposition parties from 2012, an analysis of five energy system scenarios towards 2050 has been made. These point to various ways to ensure this goal. In all scenarios, wind energy and biomass play a role, just with shifting emphasis on each, i.e. a wind scenario, a biomass scenario, a bio+ scenario, a hydrogen scenario (which includes even more wind than the wind scenario) and a reference fossil fuel scenario (Energistyrelsen, 2014a). Already today, the share of wind energy in the electricity system is relatively high, with around 34 % of national electricity production based on wind energy, around 12 % of electricity production from biomass and around 1.5% of electricity production from PV cells and hydropower. Thus, in total around 47.5% of electricity production in Denmark is based on renewable sources (Guldager, 2014). However, in terms of total energy consumption in Denmark, i.e. not just in relation to electricity, but also including energy for heating and transport for instance, by 2013, almost 27% is covered by renewable energy. Of this, the majority is based on biomass (e.g. wood, organic waste, straw, biogas), whereas wind energy is the second largest source, and solar power, heat pumps, geothermal energy and hydropower only contribute a minor share (Energistyrelsen, 2014b).

The large, and furthermore most likely growing, share of wind energy in electricity production poses a challenge for the Danish energy system for several reasons, which the smart grid can address. When the smart grid vision was first presented in Denmark around 2010, the smart grid was clearly framed in relation to expectations that wind would be the main energy source in the future system (Klimakommissionen, 2010), which required an electrification of the system. The justification of the smart grid from energy system actors (Energinet.dk & Dansk Energi, 2010) was based on the fact that wind energy is fluctuating and cannot effectively be stored. Thus, when wind energy is plentiful in Denmark, it is sold very cheaply to our neighbouring countries, which is not beneficial from a socio-economic perspective. Therefore, increased wind energy production should be combined with growing electricity consumption within the Danish borders (Ea Energy Analyses & Risø DTU, 2009), for instance through increased electrification of heating (heat pumps) and transport (electric cars). However, this would enhance classic problems with peak demand (e.g. two-three hours intense electricity use from cooking etc. between 5-8 pm), which basically creates two issues: Firstly, turning entire power plants on for a few hours of demand (reserve power) is very expensive, and, secondly, it also causes capacity problems in the distribution grid, because the cables are not rated for the much larger peaks resulting from heat pumps and electric cars. The smart grid solution has several advantages in relation to this, it was argued. Smart grid technologies can assist energy companies and households in ‘peak shaving’ – i.e. in moving their consumption to outside peak demand hours, which is a cheaper solution than expanding the distribution grid to accommodate larger peaks in demand. Moreover, smart grid technologies can also ensure that electricity consumption actually follows production, e.g. electric cars are in fact charged ‘when the wind blows’, which secures a more effective utilisation of the wind power. Smart grid technologies are also seen as a means of facilitating the integration of various storage technologies and of securing energy savings in households through automation and visualisation of electricity consumption. Finally, the integration of fluctuating wind energy also demands a balancing of the system on a much shorter time-span in order to, for example, avoid drops in frequency. Here, smart grid technologies provide better control and surveillance opportunities as well as opportunities for letting other actors such as local energy producers participate in providing these services. Thus, flexible electricity consumption from households – who are not expected to ‘suffer any comfort loss’ – was and still is a core part of the vision, and what this entails will be described in a bit more detail in the next section.

However, the integration of more wind energy or security of supply was not the only justification. Several actors also saw the smart grid as an opportunity for Danish businesses to develop new systems and products, and Denmark is already in the lead when it comes to ‘green tech’ solutions and to integrating wind energy in particular into the electricity grid. As opposed to the USA, for example, “the Danish electricity grid is well functioning and in many ways already intelligent. It has undergone a development from 15 central power stations in 1980 to a system consisting of thousands of larger and smaller power-producing units such as larger and smaller wind turbines and local combined heat and power plants” (Nyborg & Røpke, 2011: 1852). Today, Denmark has moreover become one of the leading countries in terms of developing smart grid solutions (Lunde et al., in progress: 2). Generally, the smart grid vision in Denmark is rather more complex than many other countries, for instance compared to existing demand-response programmes in the US. The Danish vision is more extensive and includes “aggregation and trading of flexibility from large to smaller consumption devices on the electricity markets” (Lunde et al., in progress: 6).

Although energy system stakeholders are working actively to create boundaries around the smart grid vision and support certain arenas of development (Jørgensen, 2012; Lunde et al., in progress), the vision is continuously being negotiated. While it has enjoyed broad support from policy makers, research and industry, lately some actors, notably in research, are arguing for leaving the strong ‘electrification’ discourse a bit to move towards a more ‘holistic’ approach. This entails integrating more elements into the vision, such as the natural gas system and district heating system. Accordingly, the system should rather be articulated as a ‘smart *energy* system’ (Mathiesen et al., 2013; Troi et al., 2013), which among other things includes large-scale energy storage and smart energy technologies that enable an efficient conversion between energy forms. This represents an alternative to flexibility services from households, for example (Lunde et al., in progress: 8). Thus, the ‘business case’ in flexible demand is increasingly questioned (Lunde et al., in progress: 14). This critique is also related to the fact that householders are not investing in electric cars and heat pumps to the extent it was envisioned, which also represents a threat to the vision – for instance, in 2010, the Danish Energy Association and Energinet.dk expected householders to have invested in 300,000 heat pumps and 600,000 electric cars by 2025 (Energinet.dk & Dansk Energi, 2010). However, as the situation is today, 5 years later, it does not seem that these expectations are fulfilled, with currently only approximately 5000 air-water and ground source (the types of heat pumps that are relevant in a smart grid context) heat pumps sold per year (Catalyst Strategy Consulting, 2013), and recent trends suggest sales may be stagnating or even falling (Andersen, 2014; Jarby, 2014). However, from the beginning, the smart grid stakeholders did not elaborate very much on how they imagined that these smart grid technologies, for example electric cars and heat pumps, could actually become part of people's everyday life, and the issue was presented more or less as something that 'would just happen'.

Although several policy measures have been taken to help them along, such as the phasing out of oil burners, which was part of the energy policy agreement from 2012, or the tax exemption and the free parking for electric cars (although the latter no longer applies), these seem to have limited effect, and biomass – e.g. individual pellet burners – represent a serious competitor to heat pumps. In relation to heat pumps, it is clear from the historical study in paper 4 (Nyborg & Røpke, in progress) that there are still institutional and regulatory issues that need to be scrutinised to enable a wider integration of heat pumps in the system and other approaches to involving householders in the process, which could be beneficial. Furthermore, more research into how these technologies interact with mobility and heating practices and systems could provide input to a discussion of the premise that these technologies – 300,000 heat pumps and 600,000 electric cars –unequivocally promote a sustainable direction, or if they may lead to changed mobility patterns (e.g. bike ride exchanged with electric car ride) and rising expectations of heating comfort.

2.1 Flexible consumers

The more specific role of households in the smart grid as it was envisioned in 2010, and which despite the above-mentioned ambiguities and controversies is still a fundamental assumption in the dominant smart grid arena, will be elaborated on next (more details can be found in paper 1). The overall goal for the ongoing iPower project, for instance – a smart grid innovation platform involving industries and research institutions – is to develop solutions to enable 'intelligent control of decentralised power consumption'. As mentioned above, a lot of the attention towards households revolves around making them use electricity 'flexibly', i.e. when it suits the system (addressing both balancing issues, congestion management and voltage control), which is opposed to the classical notion of 'predict and provide'. Thus, in the smart grid, we are moving from a "loss of supply flexibility towards a gain of demand flexibility" (Powells et al., 2014: 45). Accordingly, besides being expected to make investments in electric cars, heat pumps and possibly other smart grid technologies such as smart displays etc., households are expected to displace their electricity consumption to other times of the day. This time shift in electricity consumption can be exercised in several ways:

- Activities – such as washing clothes – can be done at times of the day when excess wind can be utilized, e.g. at night, or outside peak demand hours.
- Additionally, some appliances can store energy for later use of the appliance itself, (e.g.) when there is no wind: e.g. the battery in EVs, heat pumps with storage, or freezers that can use electricity to drop some extra minus degrees, which can compensate for periods with no electricity and thus rising temperature.
- Moreover, some equipment can store energy that cannot only be utilized by the device or appliance itself, but can also be delivered back to the smart grid system as electricity during periods with little wind and/or high demand. The battery in EVs is an example, but as this wears out the battery, it does not seem the most relevant option in the nearest future.

Moreover, an electricity system based on wind can cause sudden drops in frequency in the grid, e.g. if the wind direction changes. To reduce this problem, households can contribute 'regulating power': brief decoupling of appliances to prevent blackouts. This demands automation, since it needs to happen within seconds. Several appliances could contribute, such as freezers, refrigerators, washing machines, dryers, mobile and laptop chargers.

As mentioned above, households can also play a role in saving energy and in this way minimize the challenge of transforming the energy system. Automated energy-saving solutions that, for example, reduce stand-by consumption are seen as important smart grid technologies, but visualization of consumption is also part of the smart home. Finally, households can play a role by being energy producers that cover their own needs, and to some extent, the needs of others – they can become 'prosumers'. The smart grid can allow households to send electricity back to the grid and contribute to the production of energy. Different options exist to produce electricity, such as photovoltaics, wind, and micro CHP. This last element is, however, not very visible in the current smart grid arena and boundary making, possibly because it conflicts with the institutional and ownership strategies of the arena (Lunde et al., in progress). Other forms of micro-generation that do not produce electricity for the grid but energy for the households' own consumption include solar heat, heat pumps and geothermal energy.

As a result of the above-mentioned vision for householders, much interest is invested in exploring how much consumers for instance have to be 'paid' in order to take on this role of the flexible consumer – and what other 'motivational factors' are at play. Basically, the assumption is that the consumer besides financial incentives will need "data, education (about energy), different demand management options and new enabling technologies that will allow him to transform his home into a resource control station" (Strengers, 2013: 36). Yolande Strengers' notion of 'Resource Man' is based on over 50 publicly available international smart metering and smart grid consumer reports, which have been conducted over the last decade by or for energy utilities, governments, technology providers and behavioural economists and psychologists (35). In the 'Smart Utopia', as Strengers names 'Resource Man's' world, data along with technology simply constitute reality (30) – it is only a fraction of social life that is investigated. People's actions are defined by energy feedback and home automation technologies, and all social action is known and mediated through data (2013: 29).

The smart grid vision implies both a passive and an active role for consumers. On the one hand, it is often emphasised that 'smart home occupants' – most likely a "heterosexual nuclear family living a happy, relaxing and trouble-free life" (Strengers, 2013: 30) should not experience any comfort loss or be bothered when providing 'flexibility': the smart home "is presented as a secure site of indulgence, entertainment and relaxation" (2013: 30). On the other hand, this passive understanding is paralleled by another more active role, where consumers use for instance information on their energy consumption to take control of it – and in rare cases they are given a role as 'prosumers', whereby they produce renewable energy themselves. Accordingly, "householders are represented as both active, present and informed consumers who are in control of their energy consumption, and passive, absent and disengaged consumers who assign control of their energy consumption to technology" and "the ultimate smart consumer, Resource Man, is interested in both" (2013: 32). In any case, however, the consumer is by no means involved with 'the inner workings of the system'; instead "he can be found at the end of the supply chain, where he acts alone and autonomously, individually managing and consuming energy" (Schick & Winthereik, 2013; Strengers, 2013: 37).

Over the last 10 years the interest in 'user-oriented innovation' has grown tremendously both in business, academia and innovation policy, notably in Denmark, where it has been on the political agenda since 2003 (Elgaard Jensen, 2012; Rosted, 2003). As a consequence of this trend, tactical interest in users in relation to product development has come to involve many more academic traditions beyond market research, such as anthropology and design studies.

Accordingly, more conventional consumer research methods of segmenting consumers through quantitative approaches have for instance been supplemented with interests in people's values, interests and life styles etc. that are explored more qualitatively. Several Danish smart grid research projects have in recent years involved anthropological fieldwork and/or design thinking approaches to broaden the knowledge on the 'consumer side' in the smart grid and involve consumers more actively in the design of it. These include, for instance, the 'Minimum Configuration Home Automation' project, the eFlex project, the DREAM project, the EcoGrid project and the IHSMAG project.

These have explored how users could provide input to the development of smart grid technologies or have aimed to investigate how they use smart grid technologies (i.e. usability trials) and what motivates them to become 'smart consumers'. Although a broader perspective is included in these user studies as opposed to for example 'stated preference' surveys etc., the underlying assumption is still mostly the 'individual responsibility for change'. Moreover, energy is often purely articulated as a 'resource', 'commodity' or 'impact' as Strengers (2013) also argues, not as something that is an essential part of most everyday practices (although the IHSMAG project does in fact focus on this).

Thus, instead of exploring how these everyday life practices are performed, rationalised and organised, and how smart grid technologies interact with these or investigating the premise that smart grid technologies or the dominant ownership structures are desired, focus is more narrowly put on a few specific activities and motivations related to energy management. In other words, often, social scientists are integrated more or less as 'frosting on the cake' in smart grid projects in order to "address specific aspects of an analysis, such as to provide data on how consumers might react to smart technology, or how to best encourage them to use it" (Strengers, 2013: 27). Although such projects also produce valuable insights, in some ways they reproduce current focus on either technological change (e.g. development of energy efficient technology – eco-innovations) or on 'consumer behaviour' (behaviour change initiatives – remove mental barriers that stall the adoption of eco-initiatives), which creates a "false dichotomy in which technology and behaviour are regarded as separate solutions to the climate change challenge" (McMeekin & Southerton, 2012: 346).

Hence, such market research and consumer studies could beneficially be complemented with approaches that more explicitly pay attention to how everyday life is organised and changed, how energy consumption is a result of that and how these patterns of consumption are intertwined with technological development. Such an approach could also include insights from early STS literature (e.g. Akrich, 1992; Berker et al., 2006) "to better understand how and why new products and technological infrastructures are acquired and how they affect practices as they are absorbed into everyday ways of living" (McMeekin & Southerton, 2012: 357). As evident from the above introduction to this PhD project, I have attempted to embrace exactly such an approach; although, of course, much more work needs to be done in this area.

The next section will be reflections on the process that also includes an introduction to the eFlex project, which formed an important part of my empirical material, as well as methodological reflections. There will accordingly not be a separate section on 'methodology' in which I repeat textbook material etc.

3 The process, empirical field and methods

The overall focus of this PhD project was to investigate the role of households in a 'low carbon' transition of society. The PhD project was part of the project "SusTrans: Enabling and governing transition to a low carbon society", which operated at five societal arenas for transition. Besides households, the other arenas were 'market regulation', 'innovation dynamics', 'city structure and transport' and 'legislation on biomaterials'. When I started this research process in June 2010, the smart grid was starting to become very hyped in Denmark, and the vision made many implicit assumptions about the role householders should have in it, so it seemed like an interesting case to explore – also because the vision was still contested and the system obviously still very 'un-black boxed'.

My PhD research process has been situated in a literary landscape of design and innovation and sustainable transition research traditions. My PhD fellowship began at the Technical University of Denmark at the Section for Innovation and Sustainability under the Management Engineering department. However, as my supervisor and a large group of other researchers from the section were invited to Aalborg University to start up a new 'Center for Design, Innovation and Sustainable Transition (DIST), I followed them to the new Center at the Aalborg University campus in Copenhagen.

From the outset, the research alliance I was part of was interested in exploring the usefulness of the 'Dutch School' of Transition Theories, for instance the 'Multi-level Perspective' (MLP) on transitions of socio-technical systems (e.g. Geels, 2002; Kemp et al., 1998). The second strand of literature I started engaging with was practice theories – mostly as developed by people such as Andreas Reckwitz (2002), Alan Warde (2005) and Elizabeth Shove (Shove & Pantzar, 2005; Shove et al., 2007) - who had developed materiality and consumption perspectives in relation to practice theories. In the SusTrans subproject on households, which I was part of, we saw an important contribution in trying to combine ideas from transition theory and practice theory as a means to better account for the 'consumption side' in sustainable transition theories, notably the MLP, which was also criticised for lacking issues of power and politics (see e.g. Geels, 2011; Smith et al., 2005). Several researchers other than us ventured into this terrain at that time (Hargreaves et al., 2011; Hargreaves, Longhurst et al., 2013; C. L. Jensen, 2014; Shove & Walker, 2010; Shove, 2012; Watson, 2012) and the interest in combining these theories was also reflected in the mission statement of the 'Sustainability Transition Research Network', which emphasised that domestic actors are under-conceptualised in transition theory and the MLP. Accordingly, I started engaging with these bodies of literature while also trying to engage with the smart grid field.

3.1 First round of empirical knowledge production

As so little had been written about the smart grid at the time I started my PhD project, my supervisor and I decided that the first task at hand was to sort out what the smart grid was about – what actors and technologies were involved, what were the controversies and issues etc. Part of this process had already started when I attended the Master's course 'Mapping

Controversies', which was offered at DTU Management in June 2010. This course aimed to introduce students to the 'cartography of controversies' to explore current socio-techno-scientific issues and debates – an approach than can perhaps be dubbed the 'applied version of ANT' (Ricci, 2010). The cartography of controversies was started up by Bruno Latour 15 years ago and "has someway served as an educational version of Actor-Network Theory" – it can be seen as "the practice of ANT unburdened of all theoretical subtleties" (Venturini, 2010: 258). Although "controversies mapping entails no conceptual assumptions and requires no methodological protocols" (2010: 259) this, however, does not mean that this research technique is 'a piece of cake' and in fact it is just as complex as ANT (Venturini, 2010). More practically, the course introduced several digital tools that could be used to visualise material on the internet, i.e. to observe and represent socio-technical diagrams of controversies.

However, I did not seize this opportunity to approach the first paper in an actor-network theory perspective – mostly because I had another theoretical focus at the time – and the insights gained from the course only represented part of the research process for the first paper. Besides the research done through the Mapping Controversies course, I also set up 5 interviews with stakeholders in the smart grid field, i.e. in the energy sector, IT industry, housing industry and the Danish Energy Agency, and together with more informal conversations I had with people in the field when I attended smart grid events as well as desk studies of white papers and reports, this formed the empirical basis for the first paper. The paper was deliberately not very theoretical as we – as mentioned above – considered it to be an important contribution to 'sort out the threads' of the smart grid vision in the Danish context, but the analysis of the smart grid field and the discussion were inspired by a practice theory perspective.

3.2 Transition pathways and dead ends

The intention of my second paper was, as mentioned above, to explore whether a practice theory perspective could inform the study of transition processes. The idea was to consider the present smart grid development as a transition-in-the-making and to apply a transition pathways perspective (Foxon et al., 2010; Geels & Schot, 2007; Hofman & Elzen, 2010; Verbong & Geels, 2010) to discuss possible future pathways for the electricity system – for instance, will current developments continue, will a 'super grid' emerge or will we move towards more distributed generation?

However, although the 'electricity pathways' studies just mentioned were built on a 'conceptual refinement' of the MLP (Geels & Schot, 2007), they still mainly focused on actors on the market, policy makers, researchers, experts and their rules and structures etc. Where considerations concerning the role of households *did* appear, they were rather superficially described and the conceptualisation revolved around positioning households as either working as economically rational actors who assigned their agency to technology (a continuation of current developments pathway), or as simply not playing a very important role (Super Grid pathway), or as being engaged in developing local systems (distributed generation pathway) (Verbong & Geels, 2010).

Thus, the agency and role of households seemed under-developed in the different scenarios – although several researchers were criticising the MLP for this among other things, as I wrote above, and have been working on developing a more thorough understanding of the role civil society plays in sustainable transitions (e.g. Hargreaves, Hielscher et al., 2013; Seyfang et al., 2010; Seyfang & Smith, 2007; Smith, 2012). Nonetheless, what we also wanted to address was the assumption in the transitions literature that these different transition pathways will all lead to "substantial gains in environmental efficiency" that can "be achieved despite the expected large increase in demand" (Verbong & Geels, 2012: 209).

Therefore, we wondered whether a low-carbon transition of the energy system suggested that a broader range of roles for households should be developed than the ones that the pathways literature – and the current incumbent energy regime – envisioned. Moreover, did we need a perspective that did not take an increase in demand for granted, which the system then would 'handle', but recognized that energy systems both make and meet demand? (Shove, 2012).

More specifically, we wanted firstly to strengthen the conceptualisation of domestic actors and their different 'roles' in different transition pathways for the energy system as well as toning down this literature's sort of functionalist and un-politicised conceptualisation of the system and its actors and practices. In other words, we wanted to nuance the variety of relations households could have in the systems beyond being merely rational and individual 'consumers' in it – they could, for example, also be innovators or owners in the system (Walker & Cass, 2007) – while *also* emphasising how this 'role' should be considered something that emerged from a co-development process with the technological system through the performance of practices.

Thus, we would illustrate via, for instance, the discussion in paper 1 that the role which householders are envisioned by smart grid system builders and which they are also 'assigned' in one of the 'sustainable' pathways just described – that is, the rational, comfort-seeking consumer – would *not* necessarily lead to 'substantial gains' in terms of sustainability despite the development of a smart grid, because this system would possibly co-develop with changing practices and escalating expectations of comfort, which could increase demand. Indeed, a focus on normality as it is constantly re-performed in everyday life and not just on novelty could reveal the 'unforeseen consumption dynamics' related to the imagined regime transition.

Thus, taking a practice theory perspective, such an exploration would entail an acknowledgement that the 'demand-side' in socio-technical transitions entails more than 'user-practices' or 'markets', which is the way that the domestic sphere is dominantly taken into account or conceptualised in the Multi-Level Perspective. It also meant moving beyond seeing households merely as one of several 'relevant social groups' to be accounted for in, for example, niche experimentation and second order learning processes, which is how households are conceptualised or (theoretically) dealt with in literature such as Strategic Niche Management (Schot & Geels, 2008) – and few of these studies actually pay specific attention to users (except see e.g. Hegger et al., 2007; Hoogma et al., 2002).

Instead, as mentioned above, we wanted to make use of ideas that systems of provision, technologies and domestic practices co-develop (Cowan, 1976; Hand & Shove, 2004; Shove & Southerton, 2000; Shove & Chappells, 2001; Shove, 2003) and thus that which people actually 'do' and the practices that are performed in everyday life have importance for the systems and technologies that are developed – and vice versa. In other words, householders do not only have agency in the 'shopping'/'buying' situation or as someone who prefers or adopts or does not adopt a specific technology ("markets", "user practices"), i.e. focus is on 'acquisition rather than use', (Shove, 2012). Instead, focusing on the 'doing' and patterns of social life which technology becomes part of could also be the basis for an investigation of transition dynamics. As several researchers have pointed out, the 'socio' in socio-technical transitions remains 'punctuated in nature' (Nye et al., 2010) and "[f]or all the talk of socio-technical co-evolution there is almost no reference to the ways of living or to the patterns of demand implied in what remain largely technological templates for the future" (Shove & Walker, 2007: 768).

Such a practice theory venture would imply that households' 'role' in the system configures and was configured by certain practices – when you perform a practice you play a role in the system, or, rather, you perform the system bottom up: For instance, if people have a more 'innovative' role than the narrowly-framed 'consumer role' they are currently being ascribed, this would entail focusing more on practices that were related to user-innovations and how these develop together with systemic change. If we are often looking into 'routine' or 'consumption' practices to investigate the consumer role, we could perhaps also look into other roles and thus other practices, for instance do-it-yourself-practices, renovation practices or investment practices to discuss what these would imply for the development path of the electricity system.

What sort of configuration of practices performed by households would different future regimes entail? Considering the emergent character of 'systemic change', such a research question seems somewhat impossible to answer, but it would perhaps lead to interesting discussions anyway. Moreover, in a more normative vein, it could be interesting to start thinking about what practices would have a "system-changing character" – for instance like car-sharing perhaps – and how they could be promoted. As mentioned above, our argument was that the smart grid 'consumer role' and the practices that it seemed to entail and be configured by could easily imply an unsustainable transition. Such an exploration would also move beyond the dominant way of applying practice theory to study domestic energy consumption in everyday life and thus perhaps contribute a little bit to the development of the empirical exploration of practice theory.

Moreover, as written above, through the smart grid case, we wanted – as many others – to provide a better understanding of the 'horizontal' dynamics of regime transition and point to how it was not just policy makers and market actors etc. that have agency in socio-technical transitions. Furthermore, we wanted to bring in a perspective on the 'transition pathways' of the energy system that did not imply a privileged regime definition – i.e. that someone 'outside' the regime 'knows' what the challenges and problems are and who is going to manage the transition towards a desired 'end station' (Shove & Walker, 2007; Smith & Stirling, 2007; Smith et al., 2010). Instead we would show that the domestic sphere definitely also had a part to play in forming the pathway in an emergent fashion and illustrate how the current 'smart grid-energy system regime' dynamics are far more conflict-ridden and messy than transition theory literature suggests.

We would do this by unfolding the roles, agency and performativity of 'households' in the regime(s) in different ways. We would for instance map out the variety of (perhaps conflicting) user-constructions and scripts in different demonstration projects as well as the activities of the 'real users' with their multitude of different interests and roles at play. Moreover, we would focus on different socially shared practices that were performed by these 'users', and which orchestrate their activities, but which are also constantly changing, as roles, interests and systems are changing.

Some of these ideas were presented in an earlier version of the illustration below, which has featured in several power point presentations.

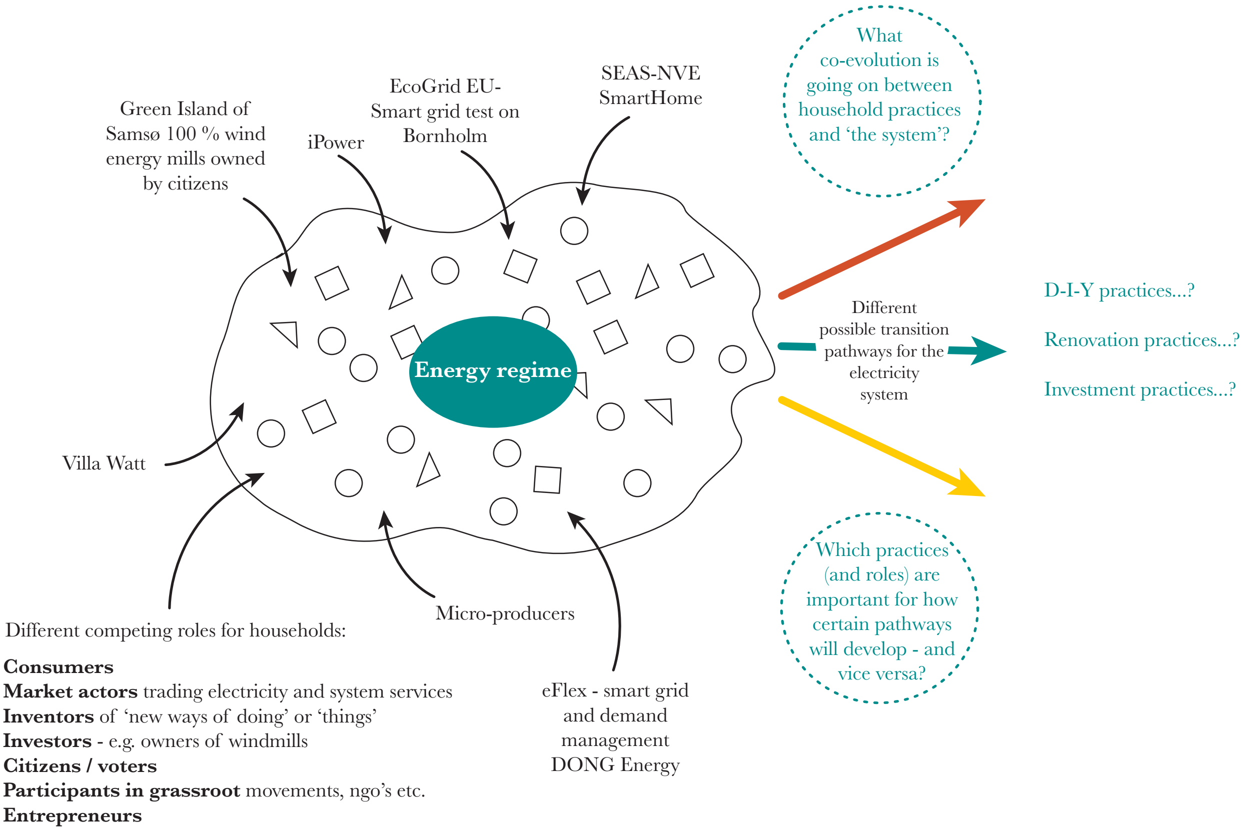

Fig. 1. Illustration of research questions (illustration by A. K. Harders)

Thus, this research process resulted in different note-papers, paper introduction-drafts and conference presentations, but the ideas never matured or resulted in an actual paper manuscript – and arguably, it seems unrealistic that all these ambitions could have fitted into one paper! We had a peer-reviewed abstract accepted for IST 2012 (see appendix), but as it turned out, we – or my supervisor, as I would be on maternity leave during the conference in August 2012 – ended up presenting a quite different paper at the conference to the one we had suggested in the abstract.

3.3 Second round of empirical knowledge production

eFlex – constructing users & conflicting knowledge interests

At the same time we had been working on these ideas throughout 2011 – while I was also attending conferences etc. and being a visiting PhD student at Eindhoven University of Technology – I had also become engaged in rather time-consuming fieldwork. Through our work with the first paper, we had gotten in contact with the project leader of the 'eFlex project', which was a project that the largest utility company in Denmark, DONG Energy's

(DE) net company, DE distribution, had initiated in the winter/spring of 2011. I became involved in that project in March 2011, and at the beginning of 2012, when the project was finished, we decided to write a paper that focused specifically on this project, since it turned out to be an interesting case of how incumbents envision and construct users in the smart grid. More details on the project can be found in paper 2 (Nyborg & Røpke, 2013: 659-661), but a brief overview is presented below, before I turn to discussing methodological issues in relation to this 'second' phase of my empirical knowledge production.

The project aimed to understand what it takes to make consumers move their electricity consumption to other times of day to avoid escalating peak loads and huge investments in expanding the distribution grid, which – as I wrote above – is one of the major concerns in relation to the smart grid in Denmark. To 'make consumers play along' and engage in a 'partnership on peak shaving', they have to be motivated, and since few households take much interest in their electricity consumption, DE Distribution expected that consumers' price sensitivity might be relatively low. Therefore, DE Distribution aimed to explore what other incentives for flexibility were in play and how these could be mobilised in the change process. To investigate this, DE Distribution hired antropologerne.com, a small consultancy company working with user-oriented innovation, service design, organisational development and communication. The consultants were to conduct a user-oriented innovation study that supported the other more technical part of the eFlex demonstration project – the testing of new smart grid prototype technologies for demand management of electric vehicles, heat pumps and domestic appliances in a number of households in DE's distribution area. The idea was, for example, to test the extent to which heat pumps could be turned off during peak hours, i.e. if people experienced comfort loss etc. Antropologerne.com was hired to investigate the assumption that customers' price sensitivity and their motivation for changing electricity consumption – aided by new smart home energy management equipment – would be strengthened if they developed a new relationship to their electricity company and to electricity as a product.

Through a range of meetings between DONG Energy and antropologerne.com prior to project start it was agreed that antropologerne.com would produce seven deliveries, which will not be explained in depth here, as this may be confidential. However, it included a segmentation of the customer base in 'flexibility profiles', so DONG Energy could 'tailor-make' flexibility solutions based on such things as their motivations. Moreover, the householder's appropriation of the equipment and their general attitude towards electricity and their general 'acceptance' of new technologies should be mapped. Antropologerne.com should also provide insights into the users' attitudes to and understandings of different pricing and tariff systems and billing. Moreover, they were meant to evaluate how much potential (online) communities – such as PODIO – had for enhancing the households' engagement in 'being flexible' and becoming 'partners'. 'PODIO' is a social media platform, which combines text, images, video etc., and where information could be shared among the participants, DONG Energy and antropologerne.com.

Finally, antropologerne.com were to evaluate the different 'communication forms' with the users to gather knowledge on how and whether the customers' attitudes towards energy flexibility could be stimulated through communicational and relational work between the customers and DONG Energy. These communication forms included a new bill and pricing system, which had been developed for the project, PODIO, customer service on mail and telephone, different information arrangements for the users and then the smart home energy management system. This smart home system was developed by GreenWave Reality (GWR) and "consisted of a main unit called a 'gateway', which is connected to the internet. The gateway communicates wirelessly with a number of intelligent power nodes that are controllable plugs with on/off control. The users could control the gateway and thus the power nodes via an online 'portal', which [the users] accessed from either a computer or from an iPod Touch. Thus, if the users connected the power nodes to appliances around the house, they would be able to see on the portal how much power each appliance consumes throughout the day" (see an image of the equipment below and in Nyborg & Røpke 2013: 660).

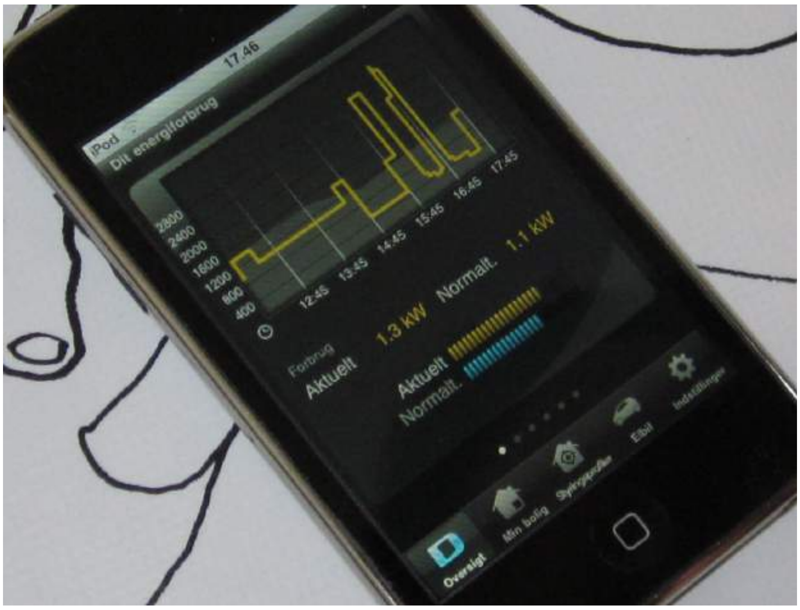

Fig. 2. An iPod Touch of one of the families. The yellow line indicates the total consumption of the house over six hours, but it was also possible to see such things as the consumption patterns of individual appliances.

Fig. 3. One of the power nodes – a power strip – is connected to 'Peter & Charlotte's' 'quooker' in the kitchen, see paper 3.

I was invited to take part in this project by becoming part of the 'analysis team' at antropologerne.com. This analysis team consisted of 10 people in total, including myself. There were 2 researchers and 8 consultants (anthropologists and designers) from antropologerne.com. My involvement meant I would conduct some of the fieldwork in the households and also participate in internal analysis team meetings, as well as participate in workshops with the DONG Energy project team, which antropologerne.com facilitated. In total 119 households were included in the project and of these 49 households took part in the user study. I performed 11 of these interviews in the period March – December 2011. However, the actual household visits only accounted for a minor part of my time spent on the project, as most of the time was spent preparing the different field manuals and on regularly reporting the findings to the analysis team. The project design included a group of households with a heat pump, a group of households with an electric vehicle and a 'control group' of 'ordinary' households without either. All three groups had the GWR energy management system described above.

The fieldwork was divided into three loops that all had a different focus. Not all team members would do fieldwork in each loop – although I did – and accordingly only about 5 people would participate in each loop. Loop 1 was executed through March, April and May 2011 and focused on the ordinary households and households with heat pumps. Loop 2 was executed through September, October and November 2011 and focused exclusively on the electric vehicle group, and loop 3 was executed through November and December 2011 and January 2012 and concentrated exclusively on heat pumps.

The final analysis and the report on the eFlex user study, which antropologerne.com presented at the eFlex conference in March 2012, were based on empirical data from all three loops. In total, this material included not only the 49 household visits, but also notes from different information arrangements for the households, such as visits to a power plant, debates on PODIO, two user workshops, three analysis workshops with DONG Energy's Team eFlex, which were performed at the end of each loop, questionnaires on demographics and life style issues and a 'choose a profile' exercise.

These different types of material are presented in paper 2, but an extended version is presented below. I have focused on the household visits, as they constituted the majority of the material.

Household visits

The household visits lasted four to five hours and often included eating lunch or dinner with the users and their families. As mentioned above, each loop would have a different field manual with an interview guide covering different themes, different cultural probes – i.e. a little assignment to be filled out by the users before the visit, such as a diary – and different types of design games or exercises that helped the informant to recall and think about motivations, feelings, attitudes, situations, people, places etc. The exercises were based on physical material, such as cards with images or with drawings made by the informant, which then formed the basis for a discussion of something specific, e.g. the placement and use of the equipment in the home or their attitude towards different devices that visualised energy consumption – for instance an electricity cord that glowed when it 'was on'. However, the visits would always start with a 'grand tour' of the dwelling, where the user would introduce the fieldworker to how they live and how the GWR equipment and/or heat pump or electric vehicle was used and what place it had in everyday life. Moreover, all household interviews included 'core questions' from DONG Energy. These were video recordings of three questions, which different members of DONG Energy's Team eFlex posed directly to the informants. These questions were screened to the informants and their answers were also video recorded. The questions, 'Why have you chosen to be part of the project eFlex?', 'What will it take for you to move you electricity consumption to night time?' and 'Could you explain to me, what it is you pay for through your electricity bill?', were questions the Team eFlex assessed as being especially central to answer in the user study.

As written above, during the visits, the field worker would video record parts of the interviews and 'use situations' and also take photos of the user and their family, their dwelling, their life style, the GWR equipment and the heat pump or the electric vehicle etc. Although there were officially 119 eFlex participants in the project, the vast majority of them lived together with partners and children. During household visits the other members of the family were involved as much as possible, as "electricity is used to create family life in the home and it is therefore not meaningful only to study the one person who is the official eFlex participant" (antropologerne.com, 2012: 18).

The first household visits in loop 1 were conducted already a few days after the introductory meeting to explore immediate problems with setting up the GWR equipment and making it 'work'. Moreover, we would interview participants on such themes as their 'electricity behaviour', relations to DONG Energy and energy consumption as well as new technologies – in fact the interviews covered ten themes to fulfil the agreed seven deliveries. In loop 1, a total of 22 household visits were conducted – 6 with heat pump households and 16 with ordinary households. In loop 2, the focus was on electric vehicles and this round of fieldwork concentrated a bit more on practices connected to the use of the GWR equipment and the electric vehicle, but also aimed at 'testing' some of the findings from loop 1 – for instance that the GWR equipment provided a 'missing link' by providing a window into the 'system behind the socket' and between our actions and the electricity consumption of the household (the bill) – i.e. that it is 'people' and practices and not the 'house' or 'things' that consume electricity; that the equipment influenced family dynamics; that it is motivating to be part of a community, and that some electricity consumption is unnecessary 'luxury', but actually hard to be flexible about, while other is 'basic' and necessary, but more negotiable. In this loop, 9 households with electric vehicles were interviewed. Moreover, 3 households with heat pumps were also visited – two of them were revisits, i.e. had also been interviewed in loop 1. The last one had also been an eFlex pilot throughout loop 1 but had not yet had a fieldworker come to visit him. Thus, a total of 12 households in loop 2 were visited. In loop 3, heat comfort practices, the use of the heat pump and the optimisation of the heat pump as well as motivations for being a 'flexible consumer' were in focus although all seven of the agreed project deliveries were investigated. Thus, the household visits also included an exercise where the informants were asked to prioritise cards with 10 different motivational factors for wanting to participate in eFlex and for being flexible that were found to be mentioned often by many of the participants in the previous two loops. However, they were for example also asked to evaluate their use of PODIO and provide responses to the new pricing system and actual bill and present input to how it could become more informative. Also, they were encouraged to talk about what the project eFlex meant for them in their own words, and how they perceived their own role in the future electricity system. I performed 3 interviews with ordinary households, 5 interviews with heat pump owners and 3 interviews with electric car owners.

Arrangements

Several 'physical' meetings were arranged for the householders to explore whether such communication channels would 'animate the householders' to become flexible partners. These included a 'question night' in loop 1 and a 'futures night' in loop 3. The latter was an arrangement at the power plant 'Avedøreværket', which included a tour of the premises and dinner for the participants. Moreover, the CEO of DONG Energy at that time, Anders Eldrup, talked to the participants about their important role in the future electricity system. Finally, information meetings that introduced the new participants to the project were held at the beginning of each new loop. I did not participate in these meetings, but attended a 'kick-off' meeting for the participants at the very beginning of the project.

PODIO

PODIO was also an important source of information about the users. Of the 119 eFlex pilots in the project, 114 of them registered themselves on PODIO during the project. PODIO was divided into several spaces: one collective space for everyone connected to the project, one for each of the three different household groups and one for the analysis team including DONG Energy's Team eFlex, which the householders did not have access to. The debate on PODIO was used as empirical data, and the idea was that it would be facilitated by antropologerne.com. Here they for instance wrote opinion pieces and shared their findings with the householders. Thus, initially, PODIO was meant to be a place where antropologerne.com could exchange experiences and discuss analytical results as well as everyday life issues and habits with the users to explore their life world with regards to electricity, their motivations and their interaction with the GWR equipment. One such example was the 'el'sk'[i] thread, which was introduced on PODIO's debate forum by antropologerne.com.

"Here, through this app, you and we together will build an alternative electricity universe – an alternative to the dictionaries of the electricity companies. Here you can put YOUR words and explanations on the electricity experiences you have had and will have with the eFlex equipment" (PODIO, April 2011)

The users were for example encouraged to describe on PODIO what they themselves in everyday life called the 'power nodes', a word coined by the system designers – e.g. sockets, power plugs, nodes, devices, 'thingies' or whatever, or they were invited to participate in a little world game called 'EL-Slang'e'. Here a moderator on PODIO started writing a word, which was connected to electricity and electricity consumption, and the participants were now supposed to find a new word, which began with the last letter in the previous word. This resulted in 103 words covering everything from "an egg boiler to gateway to element 39 (in the periodical table) – amazing and also interesting" as another moderator from antropologerne.com wrote when reflecting on the variation in areas or fields that were actually connected to electricity.

My activities on PODIO were mostly confined to the 'analysis' space (among other things to report my field work, see the next session), although I did occasionally visit the users' platform to get an impression of the activities on it.

Workshops

As mentioned above, antropologerne.com's approach was based on an applied anthropological methodology where the co-creation of knowledge was emphasised – and DONG Energy's questions and interests were literally brought into the field through, for instance, the 'core questions'. The co-creation approach was among other things reflected in

[i] 'Elsk' means 'love' in Danish in the imperative mood. 'El' is the Danish word for 'electricity'

the user workshops they held and the workshops with DONG Energy, where preliminary findings regularly would be discussed. The user workshops were designed so that typically around 5-10 users were invited to antropologerne.com's office in Copenhagen, where they would participate in focus group exercises and interviews. These events would last three hours, and parts of them were video recorded to feed into the user films that would be produced. The first user workshop was held in loop 1, and the last was held in loop 3. I did not participate in these.

During the three workshops with DONG Energy's Team eFlex, the preliminary results and findings from each loop were discussed. These meetings would also be video recorded. The workshops were typically held over two days and also consisted of presentations by DONG Energy, who would for instance report on their findings concerning the 'technical side' of the project. I participated in two of the workshops with DONG Energy, as I was in Eindhoven during one of them.

Questionnaires and choosing a profile

Towards the end of the trial period, DONG Energy and antropologerne.com decided to send out a questionnaire which 97 of the 119 participants answered. Here they answered questions on lifestyle and demographics. Moreover, all 119 users in the project were asked to place themselves in one out of five user profiles that were constructed on the basis of the 49 household visits and a user workshop with 8 eFlex participants. 72 participants chose to do this, and the results were correlated with the results from the questionnaires. I was not part of this process, however, so my knowledge on the exact rationale for them is limited – I have not used this material in my own work.

Methods of preparing and reporting fieldwork

The analysis process and the design of the field manual were ongoing throughout the project. Before field work in each loop, the analysis team – including myself – met to prepare fieldwork and discuss the design of the field manual and interview guide, exercises etc. These discussions would be based on the agreed seven deliveries, but also on the experiences and findings from the fieldwork in the previous loop. The analysis team would also participate in analysis meetings after fieldwork to report on and discuss the findings from the household visits. These meetings were also meant as preparation for the analysis/delivery workshop with Team eFlex from DONG Energy, which would follow these meetings.

Just immediately after each household visit, the field worker would report her observations and findings in field notes in the analysis teams' space on PODIO. These notes were to be filled out in a prepared template, which followed the logic of the interview guide and field manual for the loop in question. It was from the beginning of the project emphasised that the field workers should generally follow the format and methods laid out in the field manual and in the template on PODIO. All fieldworkers would have access to each others' user portraits through PODIO and these would generally contain descriptions of the participant and his or her family, their house, their everyday life routines and habits, their interests and motivations as well as their practices and experiences with the GWR equipment and/ or heat pump and electric vehicle etc. Moreover, the portraits also contained photos which had been taken in the field and which were easily uploaded to accompany the text. The user portraits were named with user number, age and name.

The user portraits did not only contain texts and photos but also contained information about income, size of the dwelling, electricity consumption per month, education, number of children, age etc. Moreover, the field descriptions were also increasingly through the loops supported by different 'percentage gradings' of such things as their interest in new technologies or their 'economy orientation', which was a way of quantifying the qualitative data. The different information in the user portraits on PODIO was automatically collected in an Excel spreadsheet, and antropologerne.com was accordingly also able to make some statistical analysis of the fieldwork.

Each video or photo that was taken during the household visits was moreover tagged with participant number and a letter signifying which household group they belonged to, the initials of the field worker and the date of the household visit. For each analysis meeting, the field worker prepared a short presentation of the informants, which again followed specific templates for presentation – e.g. a few PowerPoint slides with short bits of text and especially significant quotes and video clips – designed by the project leader in antropologerne.com. At these meetings more often than not only the project leader from DONG Energy's Team eFlex would be present, while all the field workers usually participated, including myself. During the meetings the project leader from antropologerne.com facilitated a session where field workers would brainstorm on interesting findings and observations – these findings would be written on Post-its and categorised for a further analysis process. Thus, I participated in analysing the empirical data during these analysis and presentation sessions and in developing the field manual for loops 2 and 3, while the final work with the results and writing of the report was done solely by antropologerne.com.

Different theoretical and methodological approaches

During the project, the varying backgrounds of the participants in the analysis team – consisting of me and another researcher, the anthropologists who had a consultancy role and the engineers working in an industry – posed a challenge for cooperation. The different actors had very different conceptions of what constitutes knowledge and interesting research questions, and many of the discussions at the analysis workshop were concerned with the validity of the qualitative knowledge gained from the household interviews. The Team eFlex-members from DONG Energy were particularly concerned with the issue of upscaling, generality and universality of the results, and they would quite literally ask, 'where are the numbers?' during workshop meetings, when initial findings were presented. Clearly, there were different 'cultures' at play (Snow, 1993), and some of these issues were explored in the master thesis of the other researcher in the group (Torntoft Jensen, 2011). It was often brought up that the eFlex pilots were not representative of the general customer base, as they were considered more motivated and interested in such issues as technology and energy than the general population. Antropologerne.com argued on the other hand that 49 household visits was a large data material and that an in-depth analysis of this material would provide interesting and nuanced insights despite the participants not being representative of DONG Energy's entire customer base. The DONG Energy eFlex team were, however, also often quite surprised and fascinated by the findings from the fieldwork. It came as a big surprise for many of them, for instance, that the optimisation of heat pumps did not always just 'work as expected', i.e. that people had a multitude of existing comfort practices and strategies to make themselves comfortable, which interacted with the heat pump 'optimisations' – for instance that people would just light up the fireplace if they felt cold. However, the templates on PODIO for reporting fieldwork were increasingly containing different scales in order to put some numbers on the findings as written above. The field worker had for instance to indicate on a scale from 0% to 100% what the eFlex pilot users' 'economy orientation' was, that is, how careless vs. 'penny-pinching' they were with their money or on a scale from 0% to 100% how interested they were in new technologies.

I also had issues in relation to the methodological approach. A field manual, which antropologerne.com had developed together with DONG Energy, guided the fieldwork and from the outset, it was a challenge for me to understand the rationale in the proposed methods. At the time I was not very familiar with this sort of user-oriented innovation and co-creation approaches, which included different types of design games etc. Methodologically, I was 'tuned in' to a more classic qualitative approach as performed in sociological and anthropological research communities (e.g. Kvale & Brinkmann, 2009; Spradley, 1979) and had for instance taken the 5 ECTS PhD course 'qualitative methods' in the fall of 2010, which was taught by Svend Brinkmann and Lene Tanggaard. The course included, among other things, ethical issues in qualitative research, introduction to the qualitative interview and interview analysis, participant observation and ethnographic fieldwork. Although a large part of the suggested methods in the eFlex field manual were familiar – such as semi-structured interviews, taking photos and doing 'grand tours' of the dwelling – we were not expected to sound record the interviews, but instead video record part of the interviews, use situations and the design games etc. – the parts to be video recorded were specified in the field manual. Apart from the practical problems of having to remember to video record 'the right moments' while trying to follow the informants around the house, whilst also remembering to ask the right questions and inquire into what was being said (or whilst facilitating the design game properly) as well as remembering to take photos, it also presented an issue for me that the interviews were not sound recorded at length, which was the 'normal' way to do it in my research community. Therefore, I chose to bring a Dictaphone myself and sound record the visits myself. However, as the visits would often last 4-5 hours, the Dictaphone recordings were rather long and it was – again – a major challenge to remember to turn on this device as well as the camera and video camera every time we did not 'just' chit chat. Moreover, there was also a practical problem with having only two hands and a lot of gear to carry around with me in the home. However, a cardigan with big pockets solved the problem of having to carry all the devices, e.g. video camera, camera, Dictaphone, notebook and pencils, around with me!

Nonetheless, there was definitely logic to why antropologerne.com chose the methods they did and did not rely on Dictaphone recordings and transcriptions of all of the household visits, which would have taken an immense amount of time. As the project involved a large group of people taking part in the development of insights, it was important that we reported the fieldwork in a format that could be shared and discussed in an open forum at analysis meetings and workshops – and for a consultancy firm it was also important to use methods of reporting the observations from the field that were not too time-consuming. Moreover, in general, anthropologists rarely sound record everything if they are spending prolonged time in the field, where it is much more obvious to take field notes while in the field and for instance make a field diary upon returning from it as we did.

Besides the methodological issues described above, I had, as written above, taken an interest in practice theories and had therefore from the outset a strong interest in getting to know what people *do* and how they rationalise what they do. This was both in relation to the smart energy equipment and its interaction with everyday life, but I was also interested in knowing something about people's heat comfort activities and their mobility patterns, which was also relevant to consider, as heat pumps and electric cars would be related to this. However, in order to 'get access' to the households the agreement was that I would follow the field manual and thus produce material that could be used by antropologerne.com. In return, I was allowed to use all the material that was produced, i.e. field notes, photos and video recordings from all 49 household interviews. The field manual clearly reflected what interests DONG Energy had in relation to the users, which differed from the knowledge I was interested in producing. DONG Energy were basically interested in people's attitude towards

DONG Energy and towards electricity, and they wanted to know how they could ‘animate’ people to want to become ‘partners’ with DONG Energy in peak shaving. Therefore, there was relatively little focus on ‘doings’ in relation to the home and the equipment and a lot more focus on attitudes towards electricity, climate change, environment, new technology etc., as well as questions about their ‘lifestyle’ and identity. I was not involved in the development of the field manual for loop 1, which had been developed prior to my entrance into the project, but was invited to give feedback to the field manuals for loops 2 and 3, which accordingly had a bit more focus on everyday practices including comfort and mobility patterns and use of the smart home technologies.

What my concrete contribution to the analysis process was is difficult to assess – and although it could have been interesting to trace my ideas in the process, I do not find it important enough in this context to allocate time to go back and thoroughly analyse the many, many photos I took from our ‘poster’ sessions during analysis meetings. However, I remember that my ideas were for instance related to the importance of the family ‘composition’ in terms of flexibility, that many of the eFlex pilots were very active ‘project people’ – often skilled D-I-Y’ers that liked to ‘take control’ – and that the households’ existing heat emitter systems, degree of insulation etc. were obvious to consider when a household’s flexibility potential should be considered.

Fig. 4. An image from one of our ‘poster sessions’ during analysis meetings. The pink posters are mine, and I am here pointing out how many of the users are actively engaged with D-I-Y projects.

My involvement in the eFlex project fed into paper 2 and paper 3. Although I felt I did my ‘own’ analysis in relation to papers 2 and 3 separately from the insights I helped produce during our analysis meetings, it’s obvious that the seeds for some of my thoughts were already planted at these analysis meetings.

The idea for the second paper actually came after the project was presented in March 2012 and had attracted a lot of attention. Immediately after the conference my supervisor and I agreed that I should postpone working with the other ideas we had been engaged in to focus on reporting on DONG Energy's project. As the intention of that paper was to report on the entire project, i.e. to analyse what knowledge interests such projects reflect, what they mean in relation to the development of user roles in the smart grid field in general, the analysis of the actual household interviews was not as thorough as it was in relation to my third paper. Rather, I spent a lot of time reading the eFlex project material, such as different project descriptions and memorandums that had been written at various stages of the project as well as the final report. Furthermore, I listened to an interview with the eFlex project manager that had been made by antropologerne.com right in the beginning of the project, and I also looked through videos/photos from some of the very preliminary meetings between antropologerne.com and DONG Energy about what the project should entail – before I 'came on board'.

As I came back from maternity leave in April 2013, I decided that the household interviews deserved to be explored more. Accordingly, I really 'immersed' (Borkan, 1999) myself in the empirical material from the household visits. This material consisted of the 49 field diaries (although a few of them were very short), which I had printed from PODIO and photos, videos as well as transcripts from my 'own' household visits. The five heat pump interviews were fully transcribed, as I planned to do a fourth paper that focused more on heat comfort practices and heat pumps with a colleague of mine – and we considered using interview from several projects including eFlex. The other interviews were only partly transcribed – this process is described in my third paper. The actual analysis process is difficult to reproduce meticulously, but I had among other things previously read Amanda Coffey and Paul Atkinson's chapter on Concepts and Coding in 'Making sense of qualitative data' (Coffey & Atkinson, 1996). They argue that "[a]ll researchers need to be able to organise, manage, and retrieve the most meaningful bits of our data", and that this is usually done through coding, which entails "assigning tags or labels to the data, based on our concepts" (1996: 26). Karen Golden-Biddle and Karen Locke present another suggestion for what happens from when we sit in front of the bulk of material, until we have 'written it up':

"…what we are doing is thinking about that experience in order to make some sense out of it and to gain some insights into particular phenomena, processes, and theories. In our sense making efforts, we think about the field experience in relation to other comparable situations, and in relation to what other researchers and scholars have said in similar situations" (Golden-Biddle & Locke, 2007: 13).

These accounts are probably the closest I can come to an account of my analysis methodology – I listened to the interviews and read the field diaries and my transcripts over and over, while writing notes, ideas and thoughts down in the margin of the text (what appeared to be 'meaningful bits') or in one of my countless 'ideas/notes' word files. Needless to say, such an analysis is somewhat an intuitive process that is difficult to explain.

3.4 Third round of empirical knowledge production

Heat pump controversies

While I was working on the third paper in the fall and winter of 2013, I tried to clarify the scope of my forth paper. Meanwhile, as my colleague chose to leave the institute in January 2014, my supervisor and I decided to write the heat pump paper together. I wanted to build the paper on some of the very initial ideas that my colleague had started developing, which revolved around a discussion of the conditions for a dissemination of heat pumps in Denmark, specifically focused on the role of households in this dissemination. Thus the paper would mainly build on a literature study of various Danish reports on heat pumps and a controversy mapping combined with our own qualitative interview material with heat pump users. As my empirical knowledge in the field of heat pumps was not extensive enough, I had to spend some time developing these new empirical insights by reading policy papers, existing studies of heat pump users, public debates on the subject etc., besides starting to read transcripts of the interviews with heat pump households that my colleague had conducted together with some other researchers from the institute (there were 24 in total including the 5 heat pumps interviews I did for eFlex, which we would also draw on). During this period, I wrote an extended abstract for the 'Smart grids and the social sciences' conference in Trondheim in April 2014 and prepared a presentation for the iPower conference in May 2014. This, however, was not a presentation of our paper as such (the one I had presented in Trondheim), but focused more specifically on user experiences, i.e. it was a presentation of a very preliminary analysis of the interviews with heat pump owners, which I had continued reading after the Trondheim conference.

One of the participants at the iPower conference was civil engineer Jørgen Gullev, former vice director in NESA (the biggest electricity company in Denmark until 2006, where it merged with other companies to become DONG Energy), who – despite his 84 years – was still keenly interested in the energy sector and regularly wrote magazine articles on energy policy issues etc. He approached me in a break to tell me that he had really enjoyed my presentation and that he had been working with heat pumps in Denmark for decades. Of course he was a source that was worth pursuing and I quickly arranged an interview with him and Søren Østergaard, senior consultant in the Center for Refrigeration and Heat Pump Technology at the Technological Institute. During May, June and July I did 8 more interviews with different actors in the field. The interviews all lasted around 1.5 hours; 5 of them were telephone interviews, while 5 were 'face-to-face' and recorded on my Dictaphone. Immediately after each interview I wrote down what they had told me, on average 5 A4 pages for each interview (some shorter, some longer). Jørgen Gullev had moreover brought with him two big binders with historical material on heat pumps, which he had gathered over time. As I started reflecting on my interviews and looking into this material, while I started writing, it became clear to us that the history of heat pumps deserved more attention and that the focus of the paper would change. This also meant that we had to lay aside a further analysis of the interviews with heat pump owners and instead focus on the historical material.

Thus, Jørgen Gullev's material became the basis of a more extensive and very exciting research process, which, however, was also time-consuming and at times cumbersome – the latter mostly in relation to getting access to old written material from the public administration. I had for example to gather all the regulations that had been made in relation to the renewable energy law since 1979, but the regulations that had been made before 1986 were not accessible on the 'legal information website'. Instead, our library at the Aalborg Campus had to make physical paper copies from the law gazette of these early regulations and send them to the library at the Copenhagen campus by ordinary 'snail' mail, since they were not allowed to scan them and send them via e-mail due to copyright issues. Despite the inconvenience, there was at least a logical explanation to such lengthy procedures, which, however, cannot be said about the fact that the National Archive informed me – after having communicated with them by phone several times and filling out various forms only to wait forever for a reply – that the one document I requested from them had apparently gone missing from the case it belonged to. Before this, I had been searching for the document several other places, such as at the Ministry of Climate, Energy and Building, which as far as I understood do not keep material that is more than 20 years old. It's truly an interesting experience to realise how much information actually resides 'beyond the internet'. Luckily, I eventually found out that the Parliament's information service was able to email me a scanned copy of the document.

4 Theory

The theoretical framework and conceptual resources which this thesis builds on are social theories that in different ways consider the co-constructedness of the technical and the social – in various ways they break with a dichotomy between 'the technical' and 'the social'. Rather, they see the world as socio-technical configurations and co-constructions – as connections and interactions between heterogeneous elements. They represent different ontologies, and all have different ways of conceptualising and interrogating 'individuals', 'households' or indeed 'the social', and thus have different strengths and weaknesses, but they have helped me think about my research in different and generative ways.

As evident from the introduction and the 'transition pathways and dead ends' section, practice theory has been a fundamental theory to me throughout most of my PhD process. As my papers developed, I drew on other theories to support my analysis and conceptualisation of specific phenomena and observations I came across in the field – for instance the distinct family cultures and conflicts as well as the innovativeness of many householders I observed in the eFlex project. Actor-network theory became relevant to me as I delved into the empirical material in relation to paper 4 and sensed that this was an approach that could help me enlighten the history behind the current position of heat pumps in Danish energy policy. As Nicolini (2012) writes, "a historical investigation provides vital clues to the type of power relations and interests that are inscribed in the current practice. This information is critical for those who are interested in changing (or perpetuating) the status quo" (2012: 236).

I will thus begin by introducing social practice theories and then move on to domestication theory and user innovation theory (which in many ways falls outside the socio-technical 'category', but also provides an alternative account to 'the linear model of innovation' and to the relationship between producers and users). Finally, I will make a short introduction to actor-network theory.

Each theoretical section is structured so that I start by going through the theory's fundamental ontology, and then I subsequently try to incorporate some of the latest studies that draw on this specific theory to explore the field of 'households in the smart grid/the energy system'. In this way I present a sort of state-of-the-art account in this field together with the presentation of the theories. However, I have deliberately not ventured into including all studies on users-households-consumers and the smart grid, such as stated preference surveys etc., as I have not found it relevant.

4.1 Social practice theory

My account of practice theory is informed and inspired by scholars who have developed practice theory in relation to consumption (e.g. Warde, 2005), notably domestic energy consumption (Gram-Hanssen, 2011; Shove et al., 2012) and who pay particular attention to 'ordinary consumption' (Gronow & Warde, 2001) – to how the bulk of domestic energy consumption is the outcome of the reproduction of mundane activities in everyday life. These scholars have also paid attention to the co-development between practices and technologies, products and infrastructures (Shove & Chappells, 2001; Shove, 2003; Shove & Pantzar, 2005; Shove et al., 2007; Shove & Walker, 2014) as well as to the temporal aspects of social practices (Shove, 2009; Walker, 2014). Thus, I will focus on a specific corner of the practice theory literature and by no means present a comprehensive account of what 'practice theory is' – this would in any case represent an impossible task, since practice theory is not 'a' coherent or unified theory or approach. Rather, we should talk of 'practice theories', which represent a 'turn' in contemporary sociological thought (Schatzki et al., 2001) and which constitute "a rather broad family of theoretical approaches connected by a web of historical and conceptual similarities" (Nicolini, 2012: 1). Practice theories build on work by philosophers such as Wittgenstein and Charles Taylor, sociologists such as Bourdieu and Giddens, and cultural theorists such as Lyotard, but recently the philosophers Schatzki (1996; 2002) and Reckwitz (2002) have developed a more coherent approach to the analysis of practice (Røpke, 2009: 2490).

Common for practice theories, however, is that they have 'practices' as the ontological unit of analysis and thus they provide a conceptual alternative to other forms of cultural theory, which has its unit of analysis – or locate 'the social' – in mental structures (individual minds), in symbolic structures (in symbols, texts, discourse etc.) or in interactions (for example in speech acts) (Reckwitz, 2002). By practice, it is not meant 'to practise' e.g. 'improving one's ability to do something' (Schatzki, 1996: 89) but social practices such as 'cooking', 'playing soccer', ' grocery shopping', 'commuting to work', 'shaking hands to greet', or 'watching TV'. This focus on 'practices' and their trajectories as opposed to individuals and their attitudes presents a 'Copernican revolution' (Nicolini, 2012: 9) in the way we think about the dynamics of social order and technological development.

Bridge structure-actor gap

More than other cultural theories social practice theories bridge the two classical vocabularies of social theory: that of homo sociologicus and homo economicus, or of 'structure' and 'agency', which sociological theory has dealt with for centuries (Reckwitz, 2002: 244). In this feud, social order is created and reproduced by either structures that determine human action or by self-contained actors, where society is the 'sum' of individuals who aim to further their own interests. Giddens developed his structuration theory (Giddens, 1984) to put an end to these "empire-building endeavours" (1984: 2) and argued that instead, social order is constituted by the constant reproduction of practices that create structures in society, which 'practitioners' on the other hand draw on when they perform the practices. In other words, "in and through their activities agents reproduce the conditions that make these activities possible" (1984: 2). In this way, the structures create the framework for performing the practices but the practices also have an influence on how the structure is formed. Thus, "the basic domain of study of the social sciences… is neither the experience of the individual actor, nor the existence of any form of social totality, but social practices ordered across space and time" (1984: 2). Drawing on Schatzki (2002), Røpke (2009) argues we can distinguish between 'practice-as-entity' and the actual 'do-ing' (Schatzki, 1996: 90) of the practice, i.e., 'practice-as-performance' to account for the above dynamic: individuals encounter practices-as-entities as these are formed historically and collectively – and through their own 'practice-as-performance' they reproduce and change the practice over time (Røpke, 2009: 2491). Practices-as-entities can be 'spoken about' and "drawn upon as a set of resources when doing" (Shove et al., 2012: 7) the practice-as-performance.

A practice is configured by elements

A practice is identifiable as a 'unit' of connected actions that is separable from the continual flow of other daily activities – practices can be seen as "clusters or blocks of activities where coordination and interdependence make it meaningful for practitioners to conceive of them as entities" (Røpke, 2009: 2491). A practice is thus more than 'a routinized type of behavior' (Reckwitz, 2002: 249); it is rather a "temporally unfolding and spatially dispersed nexus of doings and sayings" (Schatzki, 1996: 89); a practice consists of bodily-mental activities that are configured by several interconnected elements. These elements can be, for example, materials or 'things', bodily movements – "the body knowing how to act" (Gram-Hanssen, 2011: 64) – know how and formal rules, meanings and motivations (Reckwitz, 2002). To take 'cooking dinner' as an example, this practice requires several elements in order to be performed, such as a stove and an energy source, know-how about how to chop a carrot and meanings such as caring for your children or norms about health. Thus, practitioners provide the linkages between the elements when they perform the practice (Røpke, 2009: 2492) and, therefore, the individual becomes interesting as a 'carrier' (and developer) of collectively shared practices.

Different authors include different elements or 'ingredients' to configure the practice, but Shove and Pantzar (2005) reduce the elements to three: 'materials', 'meanings' and 'competences'. Whereas for example Giddens in his account of practices did not pay attention to the role of 'materials', the practice theorists I lean towards agree that materials, products or 'stuff' figure as an important element in practices (Shove et al., 2007). Reducing a practice to three elements in this manner is, of course, a gross oversimplification and an abstraction, but as Strengers (2013) argues, referring to Pantzar & Shove (2010), this approach is "often considered useful for analyzing and understanding the composition and dynamics of specific practices" (Strengers, 2013: 58). Just as Strengers argues, this model has helped me in drawing on practice theory as a conceptual resource when thinking about how 'energy' or electricity can be thought of as an element in many practices in a household.

In emphasizing materiality, these practice theorists have drawn on the understanding of and emphasis on materiality traditionally held in Science and Technology Studies (e.g. Latour, 1992), which "take material things beyond their largely passive role in theories of material culture, where culture is often thought to be inscribed into and simply 'do its work' on society" (Strengers, 2013: 6). Building on such positions, these practice theorists (particularly Shove et al., 2007; Shove et al., 2012) have emphasized the role of materials as actively constituting practices as they are performed. However, these authors also underline that "rather than materials being what humans tame or domesticate and appropriate through usage… the role of materials in practice is provisional and transforming: practices and their materials are always 'on the move' in a co-dependent relationship" (Strengers, 2013: 6).

Accordingly, in a practice theory perspective, resources – energy and materials – are integral elements of practices and, hence, resources are appropriated and consumed "in the course of engaging in particular practices" (Warde, 2005: 131). The interesting object of study is therefore not energy consumption in itself – we never consume electricity *to consume electricity* – but energy consumption as something that happens as a consequence of our performance of meaningful activities such as 'cooking', 'googling', 'watching TV' etc. Thus, the interesting study object is 'what energy is for' (Shove & Walker, 2014), i.e. the patterns and development of practices that energy consumption is the outcome of. This perspective radically breaks with the contention that energy production and use are "either the cause or the consequence of changing political, economic and technical systems" (2014: 42). Instead, energy consumption "is best understood as part of the ongoing reproduction and transformation of society itself" (2014: 42) – and thus "the relation between energy and society is not defined by external factors and driving forces" (2014: 42).

However, 'energy' as an 'immaterial material' element (Pierce & Paulus, 2010; in Strengers, 2013) in social practices has not received as much attention as the more 'material' elements have, and neither has there been paid as much attention to big systems and infrastructures such as the smart grid (Strengers, 2013: 7). Hence, the conceptualisation of these 'elements' and the role electricity systems play in practice need more scrutiny, although these questions are increasingly explored. However, how can we think about 'energy' as an element in practice; what role does it play? Are we talking about energy in itself or always talking about the 'stuff' (smart meters, cords, sockets etc.) that mediates energy? As Walker and Shove write, "energy supply and demand are realized through *artefacts and infrastructures* that constitute and that are in turn woven into bundles and complexes of social practice" (2014: 42, emphasis added), but does energy 'in itself' mean something for practice – for instance does it mean something for practice that the electricity is produced from wind energy? Just as Strengers (2013), I have tried to pursue these lines of enquiry in my third paper, although I had not, as mentioned earlier, read her book when I wrote the paper.

A practice is recognizable and endurable but can change

Practices are "whatever actual and potential practitioners recognize as such" (Shove et al., 2012: 82). Thus, a practice is an endurable (if it is continuously re-performed) and provisionally recognizable entity – it persist through time and space: as written above, the practice-as-entity precedes the individual who 'carries' the practice just as the idea and practice of playing soccer or cooking dinner precedes the individual player or individual 'cook' who momentarily and at a specific place performs the practice – carries out the specific 'doings' and 'sayings' – by linking the elements. For the practice to endure, it has to be reproduced, i.e. performed or enacted by many people continuously. However, through this reproduction by many different carriers who may perform the practice slightly differently and combine elements in different ways or take in new elements, the practice may change over time (Røpke, 2009; Shove & Pantzar, 2005; Shove et al., 2007; Shove et al., 2012).

Following this argument, we can both understand how practices change, but also appreciate the role 'users' – or practitioners – have for the innovation of products that are part of these practices. Importantly, innovation is not something that happens at a specific time to be followed by an adoption and diffusion phase; rather practice theorists underline "consumers' active and ongoing participation in innovation" (Pantzar & Shove, 2010: 448). As Pantzar & Shove argue, "we take all practitioners to be entrepreneurs or as others might term them, heterogeneous engineers. Critically, it is those who do fishing, cell-phoning or, in our case, walking [with walking-sticks], who integrate, and in the process transform the elements of which cell-phoning, fishing or walking are made" (2010: 449). Practices are 'configurations that work' and it is therefore not only the material element that is always 'on the move', but also the other elements that are transforming "*through* the process of doing" (Shove et al., 2012: 41).

Practice theories have otherwise been criticised for focusing too much on continuity rather than change (Gram-Hanssen, 2011). Notably Shove and colleagues have worked with improving the understanding of how new practices emerge, persist and disappear as links between the elements are made, re-enacted or broken. Such insights illuminate issues of how and why society is moving in an unsustainable direction as a consequence of the dynamics of social practices. Thus, attention has been given to how social practices change over time and what consequences this change has for the development of technological systems and for the consumption of goods and energy. Such research has also come up with ideas and strategies for how to intervene in the dynamics of social practices (Shove et al., 2012; Shove & Spurling, 2013; Shove & Walker, 2014). The dynamics of social practices not only have to do with the making and breaking of links between their elements, but also to do with how these elements are distributed and circulate. Whereas practices as situated arrangements are always in a dynamic process of formation, re-formation (they are endurable as long as they are being performed) and de-formation, “by contrast, elements are comparatively stable and are, as such, capable of circulating between places and enduring over time” (Shove et al., 2012: 44). An obvious example is related to the material element of practices and how we are surrounded by things that are no longer part of any ‘living’ practice, such as ‘old fashioned’ kitchenware. However, other elements can also ‘survive’ even though the practice it was part of has more or less died out, such as when “seemingly defunct skills are… resurrected” (2012: 44) – for instance when younger generations pick up food-preparing skills like, for instance, being able to pickle vegetables or bake bread. However, then the meaning elements in the practice this competence becomes part of (the practice is for instance no longer related to ‘a daily duty’) may have changed and so a new practice has emerged. Thus, the circulation – and ‘readily availability’ – of elements also has importance for what practices develop (Shove et al., 2012).

Practices & technology: Energy and smart grids as elements in practices

Gram-Hanssen (2011) has explored how practices related to domestic energy consumption persist or change, focusing on the role technologies play in change or continuity in practices. By drawing also on STS literatures she aims to explore how they can “contribute to the development of practice theory towards better understanding changes, including changes related to the introduction of new technologies” (2011: 65). Her discussion is accordingly informed both by transition theories and theories of domestication. Thus, through three case studies, she explores different aspects of how practices relate to technology and how practices might change as a result of a change in technology or a change in other elements configuring domestic practices.

The first case is historical and illustrates how, for instance, laundry and food practices changed with the introduction of the washing machines and freezers in homes in the 1960s and1970s. The electricity utilities had actually been trying to promote washing machines and freezers since the 1930s without any luck, because housewives were sceptical in terms of the ability of the machine to do a ‘proper’ wash and the healthiness of frozen food. However, as women entered the labour market, these technologies may have gained another meaning as being helpful or smart. Moreover, the refrigerator and freezer also co-developed with economic growth and developments in systems of provision such as with the introduction of supermarkets, which were also co-developing with infrastructural changes and urban development as people started moving to the suburbs and no longer had access to a local grocery shop. In relation to the “infusion into everyday life”, Gram-Hanssen (2011: 68) illustrates how the washing machine took part in developing new laundry practices – for instance, laundry practitioners went from washing once a week to washing ‘whenever there is something to wash’. However, the case also underlines that there is no simple relationship between the development of new products and their “infusion into everyday life”, i.e. that the introduction of a new technology will necessarily lead to new practices: this point is illustrated with the example of a woman who explains that even though she got a new refrigerator, when her husband started working as an engineer (and they could afford this status symbol), she continued shopping from day to day. It was not until the supermarkets “with their tempting shelves” (2011: 68) came along that her grocery shopping practice changed to being, for instance, once a week (see also Shove & Southerton, 2000).

The second case explores how ten families living in identical houses domesticate these houses very differently and perform dissimilar comfort practices, which results in very different energy consumption patterns. She analyses the differences in the families’ ‘comfort practices’ by scrutinizing how the various elements that are involved in ‘performing comfort’ differ among the families, which results in different practices related to comfort being performed.

Gram-Hanssen thus applies ideas from practice theory and includes four elements in her analysis. These include firstly the 'material element', i.e. the house, which is 'physically' the same in all families, but the households have domesticated the buildings differently – they for instance use the basement for very different things. Moreover, she includes elements of 'embodied know-how', 'rules and knowledge' and 'engagements and meanings'. The 'embodied know-how' element is related to how people through their upbringing and socialization come to appreciate certain things, which have become part of their bodily habits. Gram-Hanssen provides the example of a family who are sailors and used to having open windows, but who are not simultaneously attentive to regulating the heat. The second element that has an influence on energy consumption, 'rules and knowledge', is illustrated through a family with allergic children, who have got a lot of information about airing out efficiently, which means they are conversely very knowledgeable when it comes to regulating the heat. The last element, 'engagements and meanings', was also very different in the families, which also led to different comfort practices. For some families, energy savings were an important meaning element in their heat comfort practices, but again, energy savings were rationalised for different reasons, such as putting an emphasis on either not wasting money or an emphasis on environmental concerns. For most families, however, "the issue of keeping a nice, cosy and comfortable home" (2011: 71) figured as an important part of most of their comfort practices.

Finally, the third case is intended to give "insights into how routines can be changed" (2011: 71). By drawing on 10 interviews with people who were involved in a project that aimed to lower standby consumption in households, Gram-Hanssen unfolds the dynamics behind why some families on the basis of a visit from an energy advisor were able to cut back almost all their standby consumption and maintain changed routines for a year. This was partly due to a 'material' element, i.e. for instance that people rearranged their devices so that they could be turned off at once, and it also had to do with better knowledge about what standby consumption is, which implied a new meaning element of 'waste', for instance, and new skills that enabled the integration of new practices in the families' routines and so on. Meanwhile other families did not change routines, which had to do with the specific socio-technical configuration of each family: e.g. what types of ICTs did they have and what was the physical placement in the house (could they for instance be re-configured), the social organisation of the family, the meanings related to what is wasteful, and so on.

The three cases thus illustrate how both stability and change in practices are closely connected to the use of and domestication of technology. The first case presents issues of how practices and systems co-develop and co-constitute each other; the second case illustrates how the same 'technology' (the house) can be appropriated differently and lead to variations in practices related to comfort – opening for a discussion of how these variations might lead to change in the collective practices. Finally, the third case focuses on attempts to make households change their daily routines and on what elements are involved in such an endeavour. Gram-Hanssen uses the three cases to illuminate change and continuity in practices through a discussion of first, the relation between reflectivity and routines in everyday life, and second, through a discussion of how changes in one practice might influence other practices, as is also seen in technological transitions (2011: 73).

Concerning the former issue, domestication processes are interesting to discuss, as technologies might first give rise to reflections and re-configurations and later become an (unnoticed) part of the family's routines. Others (Gram-Hanssen refers to Wilk, 2009) describe the relation between reflectivity and routine in terms of shifting processes of cultivation, where routines are brought into conscious reflection and naturalisation, where a conscious act is made into routine. The project described in the last case explored exactly to what extent it was possible to induce these change processes in households, and Gram-Hanssen tries to illuminate why this change was possible in some families and not in others. By being inspired by practice theory (i.e. in this case focusing on different heterogonous elements at play relating to standby 'practices'), Gram-Hanssen shows how the specific socio-technical set-up in each family explains why some families were able to cultivate and later naturalize their 'changed standby habits' and others were not.

The second discussion revolves around how changes in one practice might influence other practices, and how some elements can belong to different practices at the same time and therefore "transfer changes from one practice to another" (2011: 63). First, drawing on Warde's (2005) discussion of change, Gram-Hanssen points to how internal differentiations within a given practice may lead to change because people integrate differing elements and perform them differently, which I mentioned previously. As Warde (2013) says, "the majority of performances are improvisations within a practice" (Warde in Powells et al., 2014: 45). This, however, raises the issue of when varying performances are part of the same practice and when they can be said to be part of a new practice? Are different ways of airing out part of the same practice or are they different practices? Do some ways of using the home demonstrate the emergence of new 'energy-saving practices'? And can there be such a thing as an 'energy-saving practice' or is this an element in other practices? Are changing habits concerning the 'turning off' of ICT a new practice emerging or are these activities part of, for instance, TV watching practices? Is laundering once a week the same practice as washing clothes in a machine daily? (Gram-Hanssen, 2011: 74).

Again, referring to Warde (2005), Gram-Hanssen suggests that individuals are "the crossing point of many different practices" (2011: 74), which implies that elements such as skills, meanings etc. acquired and 'carried' through participating in one practice may be transferred to another practice performed by the individual, which hence changes that other practice. Drawing on her own work, Gram-Hanssen illustrates how, for instance, an 'indoor climate practice' and a 'standby practice' share the 'energy-saving engagement' element. Thus, "change in one practice might thus affect other practices, because they share elements" (2011: 75) – participating in standby-reduction and the energy-saving engagement related to that activity 'spilled over' to other practices as well. Finally, big infrastructural systems are also an element in many domestic practices and, therefore, the practices are also "connected to socio-technical changes at different levels in these systems as well" (2011: 75), which is accordingly also a source for change. Big socio-technical networks and infrastructures thus link practices "at many different levels and in many different spheres with each other" (2011: 76).

This discussion of the role of technology and infrastructures for the development of everyday domestic practice is of course also relevant in a discussion of the role of households in the smart grid. Like, for instance, Gram-Hanssen (2011), I have grappled with how to conceptualise the role of technology and networked systems for domestic practices – also for practices that are complicated and inter-connected and less easy to delineate than the practices that have often been used as cases for developing practice theory, like showering, Nordic walking or driving (Hand et al., 2005; Shove & Pantzar, 2005; Warde, 2005). This is also what Strengers (2013) has pointed to as needing more attention, as mentioned above. She argues that "larger systems of resource provision and their associated technologies have had a more ambiguous status in practice" (2013: 64), and that practice theory literature does "not position the energies produced and delivered by large or small-scale energy systems, smart grids or other energy technologies as part of practice itself" (2013: 64).

In her book, Strengers (2013) first unravels the dominant imagery of the Smart Utopia and Resource Man, and then she explores, one by one, four smart grid strategies, i.e. 'energy feedback', 'dynamic pricing', 'home automation' and 'micro-generation', to understand "how the smart ontology on which these strategies are founded is being performed by householders through their everyday practices" (2013: 73). Interestingly, all four of these strategies were to various extents part of the eFlex project I took part in.

Discussing energy feedback, Strengers argues among other things that the narrow focus on 'energy' feedback has limited potential for reorienting domestic practices. This is because 'energy' and measuring it in kWh is not a meaningful part of most of our domestic practices – 'number' or 'kWh' feedback in this way is not an integral element needed to perform many domestic practices (not yet, at least), as opposed to many fitness practices - for instance, where measuring performance has become a meaningful and necessary element. Rather social, material and sensory feedback are an "integral part of the ongoing performance and transformation of everyday practice" (2013: 93).

Dynamic Pricing and in particular Critical Peak Pricing (CPP) events, on the other hand, have some potential in disturbing routines and rhythms in everyday life, because they temporarily disrupt the meanings of electricity within the practices that use it. Thus, in these CPP events, electricity acquires (although only temporarily) new meanings of frugality and finiteness, which electricity otherwise does not have as a logical consequence of the historically dominant 'predict and provide' approach to energy supply.

Concerning Home Automation technologies, Strengers argues that although "they are intended to passively and silently operate in the background of everyday life", these can indeed "have highly visible effects, bringing new meanings, materials and skills to everyday practices, and enabling their movement in time and space" (2013: 116). Strengers starts, however, by warning that home automation features such as 'direct load control' or other ways of assigning control to technologies, which aim to "maintain energy's largely invisible and passive position in practice" (2013: 117), may serve to legitimise more energy-consuming practices. Moreover, home automation visions that seek to make everyday practices "more enjoyable and pleasurable" − whilst also 'smart and efficient' − may also "realise more electricity-demanding expectations of comfort, cleanliness, convenience, entertainment and security; expectations that undermine the aims of the Smart Utopia" (2013: 117). However, Strengers also demonstrates that fully-automated smart homes, for example, can 'act back' and make their own demands on practices, such as when an automated light turns off in a room, thus sending a message to the occupants to go to bed for instance. Smart homes are therefore "making suggestions that potentially reconfigure the existing constellation of practice elements" (2013: 131).

Finally, concerning micro-generation, Strengers outlines how "different energy systems constitute *energy-making practices* − that is, practices of making energy in different ways" (2013: 131). She moreover positions the energy that is made through these energy-making practices as a material 'thing', and she discusses how 'energy-as-material' "meets with the constellations of other materials, meanings and skills" in everyday practice (2013: 135). Strengers argues that micro-generation actually has the potential of 'mattering' to practice, i.e. the ability of energy "to become integrated into everyday practices in ways that shift or shed energy demand". Some of her arguments are concerned with how, firstly, the work put in producing energy changes the meanings related to this 'home-grown' energy, which becomes more tangible and less available. Secondly, she points to how different ways of producing energy, for instance, wind energy vs. PV on a roof top, produces different ‘energ*ies*’ (not in a strict ‘physical’ sense of course), which has implications for when and how domestic energy is consumed, i.e. we can start talking about “windy day laundering and sunny-day bread baking” (Pierce & Paulus, 2012 in Strengers, 2013: 148). Thus, ICT-enabled micro-generation brings specific spatial and temporal constraints to practices of making energy and to the practices that use these energies” (2013: 147). Referring to Røpke & Christensen (2012), Strengers argues t this tightening and coupling of time and space provide an interesting contrast to other studies that have shown how ICT’s have supported a decoupling of time/space constraints of many practices. This decoupling is also what Strengers argues, for instance, conversely creates opportunities “for CPP to facilitate the shifting of routines to different times of the day” (2013: 147). Moreover, smart homes can allow for certain practices to be performed from other places through, for instance, automation (2013: 147). In the perspective of large-scale energy production, it also matters when you perform a practice as it can be more or less ‘carbon intensive’ depending on whether you, for instance, perform it at night time where the nuclear base load – in a UK context – powers night-time demand (Powells et al., 2014: 45) or in periods when, for example, national wind energy production is high.

Practices, structure and flexibility

As evident from the last part of the above theorising, issues of time and space in relation to practices and ideas about how practices relate to each other are of course also relevant for an exploration of smart grid strategies such as ‘flexible demand’. Sticking to the focus on ‘what energy is for’ and the claim that energy demand is a result of the dynamics of practices, such a focus says something about the temporalities and ‘flexibility’ of energy demand. Changing the duration or spatial-temporal location of practices, for instance by attempting to move energy demand ‘away’ from peak hours necessitates an investigation of “the complex temporal organisation of everyday life” (Shove et al., 2009: 1) and “the interweaving of personal and collective logistics” (Shove et al., 2009: 17). Practices are not ‘free-flowing entities’, but are often bound in bundles and complexes with other practices and performed at specific times and places – there is a certain rhythm and synchronisation in the performance of practices (Shove, 2009; Walker, 2014).

Time and space

In a practice theory perspective, it can be argued that time is made up by practices – ‘practices make time’ (Shove, 2009: 17). As Shove (2009: 19) formulates it, “the weekend *is* the weekend precisely because we do things on Saturdays and Sundays that we don’t do on Mondays and Tuesdays”. In other words, “people distinguish between weekdays and weekends because they do different things on different kinds of days” (Røpke, 2009: 2492). Practices thus make time – they *produce* time (see below on rhythms) – but they also *consume* time (Shove, 2009). Time is an integral part of a practice since it, for example, takes a certain amount of time – and often “things have to be done in a particular sequence” – (Røpke, 2009: 2492) to carry out a practice in a ‘proper’ way. Thus, “the ability to time various activities correctly can be an important part of the competence involved in the performance of the practice” (2009: 2493). Our experience of time is accordingly a result of our performance of practices. Both time and space are hence important for the coordination of everyday life. Røpke (2009) discusses practices and issues of time and space by drawing on among others, Pred (1981) and argues that time and space are limiting factors for the amount of practices one can become carrier of at the same time. As noted above, practices take time to perform; they compete for individuals’ time as “time spent on one practice is not available to another” (Shove et al., 2012: 105) and there are (despite the emergence of the internet etc.) limits to the “simultaneous participation in spatially separated activities” (Røpke, 2009: 2493).

Bundles and complexes – paths and projects

Moreover, as pointed out before, most practices do not exist in isolation, but are linked to other practices in 'bundles' or 'complexes': "Bundles are loose-knit patterns based on the co-location and co-existence of practices. Complexes represent stickier and integrated combinations, some so dense that they constitute new entities in their own right" (Shove et al., 2012: 81). As Strengers argues, this is notably important for everyday practices that consume energy, since many of these are "woven together in various temporal routines within the home" (2013: 58), such as when cooling or heating the home is closely linked to other practices such as caring for the sick or working from home. The observation that practices are often bundled with other practices is thus also important in relation to the smart grid vision for households, since the strategies, such as flexible demand, that the vision entails – which in a practice theory perspective means that practices are dislocated in time (and place) and new elements are introduced – are only considered to be relevant for or impinge on a few practices, but these strategies may come to have consequences for a range of practices they are bundled with (see also paper 3). The introduction of Smart Utopia strategies involving flexible demand "enables the emergence and integration of new materials, meanings and skills into a variety of everyday practices, which may transform entire bundles or complexes of practices rather than single and isolated entities" (Strengers, 2013: 58).

Moreover, the life path and daily path of the carriers of practices, and the projects they engage in or are recruited to, also have importance for how practices are organized in relation to each other (see Røpke, 2009; Shove et al., 2012). As Røpke (2009) argues, "each individual follows a path in time and space, each carrying out practices that take up time and have to take place in space" (2009: 2492) and this also implies 'so-called coupling constraints': "As practices often involve other people, other living organisms as well as man-made and material objects, they depend on the coupling and uncoupling of the paths of all these human and non-human "partners"' (2009: 2493). Projects organise what practices we take up, such as when the project of starting a family, renovating the house or getting a pet requires that certain practices are performed in specific ways and at specific times and places to 'do the project'. Thus, projects also help organise the coupling of the different paths of individual carriers. Co-performed practices, such as having a 'family dinner', also organise the coupling of several paths and therefore these co-performed practices may be less flexible in terms of moving them in space or time. Nonetheless, a household consisting of multiple daily paths requires 'strict' organisation and coordination in everyday life, and this accordingly has implications for the temporal-spatial flexibility of practices performed in such a household (see also papers 2 and 3 on this). Moreover, projects and practices that are strongly governed by institutions, i.e. regulative systems, normative systems and cultural-cognitive systems (Scott, 2001), may also be more 'inflexible' in terms of change. To take the example of family dinner again, this practice is perhaps more institutionalised than for instance doing the laundry, I would argue, as there may be stronger norms connected, for instance, to how, when and where we should perform this practice. The discussion of 'projects' also involves interesting perspectives on issues of power (e.g. are the projects defined by individuals or 'by' institutions, and who gets to decide the dominant projects – and thus practices – in society?) and path dependency, although these issues will not be elaborated on here (but see, for instance, Shove et al., 2012 and Røpke, 2009 for an elaboration).

However, more concepts than bundles, complexes, projects and paths are needed in order to characterise the link between practices and their organisation. Understanding the rhythms of practices and their synchronization also presents insights into the production and reproduction of certain links between practices that present 'structures' in everyday life.

Rhythms and synchronisation

As argued above, smart grid strategies, such as postponing laundry to night-time, may impinge on other practices than the ones that are in immediate focus – in papers 2 and 3 we, for instance, discuss how postponing laundry may also be problematic for the drying clothes practice it is bundled with. Thus, these strategies may also disturb the everyday life 'rhythm' in unexpected ways, such as when postponing laundry necessitates that clothes need to be hung up in the morning, which conflicts with other recurrent activities, such as getting the children ready for school or making their packed lunches. This 'breaking' of the relation or connections between practices is problematic since it is important in "organising, ordering and pacing the activities of their practitioners – their humans" (Powells et al., 2014: 45).

As Walker (2014) writes, "[r]hythms of various forms pervade everyday life, providing temporal structures that organise and order repetitions within the complex, ongoing flow of the social world" (2014: 53). Rhythms are "achievements of coordinating and stabilizing relationships between practices" (Shove et al., 2009: 10). They are "essentially patterns in the routinized or habituated doing of practices in similar ways at similar times (eating, sleeping, washing, for example), and/or functional coordination of different practices into connected sequences (waking, then dressing, then eating, then travelling, then working and so on)" (Walker, 2014: 53). Thus the rhythms of society are constituted by the many practices of people and organisations that over time reproduce similar patterns of coordinated activity (Walker, 2014: 53). These rhythmic patterns can moreover follow daily, weekly or annual cycles or scales, for instance, recurrent weekends or summer holidays etc.

Multiple 'energy rhythms' exist within different bounded spaces or spatial units such as in households, organisations etc. (Walker, 2014). However, 'peak loads' bear witness that many rhythms are collective or 'synchronised' in some way or other. Thus, "questions of synchronicity have been seen as fundamental to the relation between time, everyday life and the reproduction of social order" (Walker 2014: 54). Walker discusses how synchronisation is increasingly "significant to the reworking of energy systems" (2014: 54) and he distinguishes between 'social synchronisation' and the synchronisation between natural and social rhythms, which he calls 'natural-social synchronisation'. A classic example of social synchronisation is meal times – when (where and how) you eat breakfast, lunch or dinner is more or less synchronised across society – and such synchronisation "generate[s] aggregate patterns of rhythmic load on grid infrastructures and, in particular, peaks in energy demand" (2014: 54).

Rhythms are of course also evident in the world of nature, where Walker argues that sun (light) represents an obvious example, since the sun "generate[s] an important sense of rhythmic patterning to light-demanding social practices" (2014: 54). In other words, natural-social synchronisation is about synchronising social practices with the 'rhythms in nature'. Walker argues that the siesta represents an "illustration of a matching between the social rhythms of practice and the natural rhythm of the temperature in the middle of the day" (2014: 54). Nonetheless, such synchronisation with 'natural rhythms' has increasingly disappeared (e.g. siesta replaced with air-conditioning) with increasing energy consumption as a result (Walker, 2014). However, with the new challenges arising from the energy system transition and the smart energy system visions implying among other things the integration of more renewable energy sources, Walker argues, these synchronisation issues are becoming increasingly important. Aiming to match energy consumption to intermittent energy production (some renewable energies more 'rhythmic' than others, e.g. tidal wave relative to solar or wind for instance) as opposed to the other way around "is very much on the table" (Walker, 2014: 56). Returning to Strengers' (2013) discussion, thus, the otherwise increasing 'social de-synchronisation' trend that ICT enables (through loosening of spatial-temporal links between practices) is opposed to how ICT on the other hand is increasingly positioned as a means to 're-synchronise' the otherwise diminishing relationship between natural and 'social' rhythms. This diminishing synchronisation can for instance also be seen through the notion of the 'society without seasons' "in which seasonal services, such as ice-skating or skiing, or indeed getting a suntan, are made available all year round" (Walker, 2014: 56).

Flexible practices

To sum up: Peak loads are constituted by synchronised rhythms of energy-consuming practices, and understanding how these practices can be re-organised requires first a 'deconstruction' of the load (Powells et al., 2014) and an exploration of what practices are performed and how they relate to each other. As I am arguing in paper 3, it matters for the 'flexibility potential' of a practice how tightly coupled it is to other practices and how it disturbs the daily 'rhythm' – for instance, washing and drying clothes often go together as mentioned above . Another example could be that lighting up the fire place and entertaining guests (or grand children) go together, albeit more loosely. Furthermore, as I and Powells et al. (2014) also point out, practices that are co-performed, such as 'family dinner', require the establishment of "a shared 'pulse' – a time and place at which the rhythms cross" (2014: 48) or as I write, co-performed practices are nodes that couple multiple individual paths. Although 'laundry practices' can be coupled to many other practices as written above, they may have more flexibility as they are 'solitude' practices that only need to engage one carrier at the time – and as I argued above, laundry practices also seem to be less constrained by conventions and norms about when they should be performed compared to, for instance, 'dinner' practices (Powells et al., 2014). Thus, Powells et al. (2014) argue that the flexibility of domestic practices is to a greater or lesser degree constrained by on the one hand their (poly)rhythmic qualities and on the other hand their position in relation to conventions and norms.

Despite for instance differing national contexts, there are very similar findings in the project by Powells et al. (2014) and myself in terms of the relatively high degree of flexibility in laundry and dishwashing practices compared to other practices that could constitute the peak load, such as TV watching, cooking, dinner etc., which seem more 'inflexible'. However, these practices such as cooking and dinner do not necessarily have to be moved in time but could also become less energy-intensive by a reconfiguration of the elements of which they are made. This could for example involve 'slow-cooking' equipment (Powells et al., 2014) or new conventions concerning the 'normality' of eating warm meals during the evening peak – several of my eFlex informants for example suggested they could perhaps eat cold food for dinner instead of warm.

4.2 Domestication theory

Critique of linear model

As a response to the 'linear model of diffusion of technology' (Rogers, 1962), domestication theory arose in the late 1980s and the 1990s in communities of consumption & culture studies and in media & communication studies (e.g. Silverstone & Hirsch, 1992) as well as in science- and technology studies (e.g. Lie & Sørensen, 1996). The linear model has at its heart an idea that there is a "linear flow of knowledge from research and development to everyday life" (Hyysalo et al., 2013b: 491), which means that the meaning and use of technologies by and large follow the intentions of the designers and are quite predictable. Following this model, the adoption of new innovations is "rational, linear, monocausal and technologically determined” (Berker et al., 2006: 1). Accordingly, from this perspective, the main obstacles to a sustainable transition and a ‘flow of adequate energy technologies’ into people’s homes, for instance, can be the ‘non-technical’ or ‘social’ barriers (Hyysalo et al., 2013b; Shove, 1998) such as ‘unfortunate’ consumer attitudes and perceptions of technology (Hyysalo et al., 2013: 491). Hence, these perceptions and attitudes predict user adoption and need to be overcome or manipulated to achieve diffusion of home energy management technologies or energy efficiency gains.

Taming unfamiliar technologies

In contrast, the domestication concept “considers the complexity of everyday life and technology’s place within its dynamics, rituals, rules, routines and patterns” (Berker et al., 2006: 1). The approach argues that technologies do not have ‘a priori’ inherent characteristics – they are not universally defined or unchangeable entities that determine ‘human behaviour’ – but rather, the understanding, meaning and use of technologies is highly complex and dependent on the specific context of the everyday life they are integrated into. The notion of ‘domestication’ refers to the ‘taming’ of the new, strange, unfamiliar and ‘threatening’ technologies, which enter the household as wild animals and have to be ‘housetrained’ – i.e. they threaten to disturb the moral and temporal (and spatial) order or the identity, rhythms and practices in the household, which have already been negotiated and established, although constant work is needed to ‘uphold’ this order. Accordingly, the artefacts may have to be remade to fit into this context. They are incorporated into the domestic culture and redefined in different terms, “in accordance with the household’s own values and interests” (Silverstone et al., 1992: 16). On a symbolic level, ICTs, just like pets, can become part of the family and if domestication has been successful, the objects are no longer regarded as cold and problematic consumer goods ‘at the root of family arguments’, “but as comfortable, useful tools … that are reliable and trustworthy” (Berker et al., 2006: 3) – they have lost their magic and news value and are eventually taken for granted. However, some “technologies continue to ‘disobey’ and ‘just as young puppies (and older dogs) can cause damage in the household and arguments between family members, the domestication of technological artefacts is seldom complete” (Berker et al., 2006: 3). The domestication approach also opens up the ability for producers, regulators and so on to attend to why technologies are often transformed and not used as they were intended to or in many cases rejected entirely (Silverstone & Hirsch, 1992; Berker et al., 2006).

ICTs are doubly articulated

Domestication theory is especially concerned with information and communication technologies (ICTs), which have the special characteristic that they are both artefacts and mediated content – they differ from ordinary material objects of consumption research (Livingstone, 2007: 2). The introduction of a TV into the home, for example, both introduces a new material and symbolic object into the home as well as TV programmes, news, films etc. This can equally be said about smart home technologies such as ‘in home displays’, which both present physical artefacts and ‘mediated content’, i.e. information about dynamic electricity prices etc. Thus, it is not only the physical object which has to find its time and place in the fabric of everyday life but also the information and communication it enables, which adds an extra dimension or a ‘second articulation’ (Silverstone, 2006: 239). This means that they are doubly articulated into domestic culture. As Silverstone puts it, ICTs are not inert like washing machines (2006: 239-240). These content-based claims establish, but also disturb, “the relationship between the private and the public spaces of communication and meaning” (2006: 240). ICT provides (or fails to provide) “a route for the consumption and articulation of publicly-generated messages … that feed back into the home and for privately-generated messages …to be circulated in return” (Silverstone et al., 1992: 21).

Consumption is production and domestication is a dual process

Domestication can be seen as a process of consumption, which is active instead of passive and where engagement with the artefact draws on "personal, social and cultural resources in such a way as to leave the original, if such a thing could be identified, as significantly affected in use" (Silverstone, 2006). In other words, consumption is also production and "studying acts of domestication is similar to studying acts of design and innovation" (Lie & Sørensen, 1996: 8). Thus, 'technologies are both shaped and shaping' (Silverstone et al., 1992: 26) in domestication processes. Domestication is a 'dual process' in which both technological objects and people may change – the objects may be ascribed new meanings and functions but they may also assist in breaking habits or developing new routines and identities in the home or another community or social organisation where a specific 'moral economy' is at play (Oudshoorn & Pinch, 2003: 14). During the domestication process, established social arrangements and cultural values at individual and collective levels are confronted and are changed by the technology, which in turn is also changed. "Both parties to the interaction, the human and the technological, and in both material and symbolic ways… are in a constant dialectic of change" (Silverstone, 2006: 232) or as Aune (1996) puts it, it is "a two-way process in which both technology and humans are affected, and in which both technical and social features are changed" (1996: 92).

The moral economy of the household and negotiations on technology

The notion of the 'moral economy' signifies the 'moral and temporal (and spatial) order, rhythms and practices' mentioned above. The moral economy of a household is a "locally constructed cosmological order" (Hirsch, 1992: 120) or a "particular and unique culture, which provides the basis for the security and identity of the household or family as a whole, as well as that of its individual members" (Silverstone et al., 1992: 18). However, that does not mean the household is not also at times a place of conflicts and negotiations between the household members, which only over time "work themselves out' given the moral economy within which the members exist"(Hirsch, 1992: 120). These 'distinct moralities' in the household are made particularly explicit through domestication processes (Hirsch, 1992: 120). The role of technology in a household is thus a product of negotiations (Aune, 1996: 101), and "everyday struggles and negotiations may have important effects on the shaping of technologies and its 'consequences'" (Lie & Sørensen, 1996: 11). The specific domestic setting and family structure thus have an influence on how things are 'consumed'.

Moral economy vs. formal economy

The *moral* economy is thus defined by a kind of 'common sense' or 'signature set of values'. It is 'grounded in a sense of self' and represents ideals "of appropriate values and behaviour that are equivalently (and by definition) sustaining of identity and culture" (Silverstone, 2006: 236). Importantly, also, the moral economy of the household protects the household (or other community) from the "traumas of the public and the mediated world" (Silverstone, 2006: 236). Domestication bridges a priori the macro social and the micro social (2006: 233) and domestication theory is especially attentive to dynamics concerning the borders or the transactions (or the threshold) between the household and the 'outside world' – to the relation between the logics of the household and the more 'formal' logic of the public economic world. The principles of the market economy will not necessarily play out in the setting of the household, where the abstract value of money is not upheld (Silverstone, 2006: 236). Unlike commonly-held ideas about the workings of the formal economy, rational actors who are constantly and independently seeking to maximise profit do not populate households. In other words, the morals of the household are often based upon a non-rationalistic set of values of reciprocity, exchange and personal valuation, which are distinguishable from the dynamics that operate in the public sphere (Silverstone et al., 1992:

18). However, the moral economy of a household is also a moral *economy* because the household and the productive and consumptive activities of its members are involved in the public economy. It is part of a transactional system, "dynamically involved in the public world of the production and exchange of commodities and meanings" – as well as being a "complex economic unit in its own terms" (Silverstone et al., 1992: 18). Moreover, all economies are moral in the sense that they prescribe relationships between participants in a system, which are seen as both desired and optimal and thus have "inbuilt judgements of value" (Silverstone, 2006: 237).

Elements of domestication

In the seminal book 'Consuming Technologies' from 1992, Silverstone et al. described how the moral economy is expressed in four non-discrete phases in "the transactional system of commodity and media relations" (1992: 20). Splitting the process of domestication into these partial processes makes the domestication process more analytically tangible (Aune, 1996: 94). These were phases of 'appropriation', 'objectification', 'incorporation' and 'conversion'. However, Silverstone later changed the too general term 'appropriation' to 'commodification' (2006: 233). Commodification refers to the very initial phase of domestication – actually to the time before, and as the product enters the household. In this component of the domestication process ideas about the potential user, which are inscribed in the technologies as well as public policy etc., 'prepare the ground for the initial appropriation of a new technology'. Thus, in this dimension "negotiations and considerations that lead to the acquisition of technologies" (Haddon, 2011: 312) are also captured. As Silverstone (2006: 234) expresses it, "machines and services do not come into the household naked". The 'conversion' element is the opposite process, in which the household's moral economy and the household's specific appropriation and understanding of the technology or media content – the domestication of the artefact or meaning – is signified to the outside world (Aune, 1996). Like other objects in our environment it becomes part of our cultural identity and capacity, which we like to showcase to the world (Aune, 1996: 92). "Consumption is never a private matter, neither phenomenologically nor materially" (Silverstone, 2006: 234) and conversion signifies how we 'tell about' and 'show off' ICTs we have appropriated. Like the commodification element this element is about the households' relation to the outside world and the boundary through which texts and technologies "pass as the household defines and claims for itself and its members a status in neighbourhood, work and peer groups in the 'wider society'" (Silverstone et al., 1992: 25). The objectification and incorporation components of the domestication process are about the physical placement of the artefacts and media content in time and space. The objectification component is about how ICTs are placed in the home spatially; they are given a place and made visible to the users (Aune, 1996: 94). It is about how the household presents its aesthetic values (Aune, 1996: 94) – about location "in the material, social and cultural spaces of the home" (Silverstone, 2006: 235). Incorporation, on the other hand, is about "the injection of media technological practices into the temporal patterns of domestic life" (2006: 235). In the incorporation component of domestication, the ICTs are incorporated into routines and values systems of everyday life and the 'existing patterns of social life', which are never left untouched, as Silverstone (2006) argues: "new machines claim new spaces and new patterns of participation; new content challenges existing rules of behaviour or codes of familial practice" (2006: 235).

Developments of domestication theory

Even though domestication theory has traditionally been especially concerned with the use of technology in the specific location of the home (Oudshoorn & Pinch, 2003), other domains have later been explored (see for example Berker et al., 2006; Lie & Sørensen, 1996) and the notion of 'home' or 'domesticity' as being localised at one specific place has been criticised (see for example Morley, 2006). Moreover, domestication theory has been criticised for focusing in the beginning on how it was only the technology that had changed and not humans or social structures. It has furthermore been argued that as domestication theory was first developed it proposed too linear a model itself, through, for instance, the conceptualisation of the elements or phases of the domestication process as consecutive. These were seen as initially being formulated as too discrete and linear and suggested there was an end goal in the process. Roger Silverstone (e.g. 2006) and others have later emphasised how "processes of domestication and scripting never end" (Shove et al., 2007: 149), and that the phases should not be seen as discrete or 'linear' phases that substitute one another. Rather, they should be seen as components or dimensions of an ongoing process in which the moral economy of the household is also made and shaped by trajectories of human-material and material-material complexes that co-evolve and are formulated through enactments of practice (Shove et al., 2007: 149). In short, users "do not impose a linear career onto their technology" (Ward, 2006: 159).

Domestication of energy technologies and everyday practices

As written above, domestication theory was originally developed mainly in relation to the field of ICT in the home, but other domains or social contexts (for instance in businesses or in educational settings) and other types of technologies, such as cars and ultrasound technologies, have also been explored from a domestication theory perspective (see for example Berker et al., 2006; Lie & Sørensen, 1996). In relation to the field of domestic energy consumption, several studies have drawn on ideas from STS literatures such as domestication theory to explore the socio-material and cultural dynamics that have an influence on domestic energy consumption (e.g. Aune, 2007; Gram-Hanssen, 2004), and how householders domesticate and interact with smart energy monitors (Hargreaves et al., 2010; Hargreaves et al., 2013; Wallenborn et al., 2011). The energy impact of the domestication and integration of ICT in everyday life has also been studied (J. O. Jensen et al., 2009), also from a practice theory perspective (Røpke & Christensen, 2012). In relation to renewable energy technologies, Juntunen (2014) presents an interesting study of the domestication of individual, small-scale technologies such as heat pumps, wood pellet burners and PV solar in Finland. In this study he develops the concept of 'domestication pathways', which has a slight resemblance to the concept of parallel domestication I describe briefly in paper 3. We share the point that multiple domestication processes influence each other, but we have different 'temporal' foci – whereas I am concerned with how the domestication of an artefact assists the simultaneous or parallel domestication of another artefact, domestication pathways describe how the domestication of one artefact "creates and produces practices that lead to the adoption of new technologies and practices". Thus, the domestication of an artefact leads to the subsequent domestication of another and accordingly "multiple domestications can be linked and lead to adoption of new technologies without a stable final point" (Juntunen, 2014: 9).

Kirsten Gram-Hanssen has also more recently (2011), as discussed above, suggested bringing in ideas from domestication theory to explore how such STS literatures "can contribute to the development of practice theory towards better understanding changes, including changes related to the introduction of new technologies" (2011: 65). By using ideas about the 'conversion phase' of the domestication process, where we 'showcase' our appropriation of the artefact to the world, Gram-Hanssen argues that "by this we might take part in the development and change of the practices, as others might respond to our ideas and use them as well" and thus "the processes of domesticating technologies is a process of changing relations between what holds practices together" (2011: 66-67). This is another way of articulating and explaining how it is that 'innovations in practice' – or rather, a practitioner's situated way of performing a practice-entity differently by integrating (new material) elements in new ways – spread and capture other practitioners. Moreover, the engagement and adaption of the artefact is also a process of transforming rules and explicit knowledge "into routinized behaviours and tacit know-how and this involvement with the products might influence the engagement [meanings] included in the practice" (2011: 67).

McMeekin and Southerton (2012) also suggest drawing on both social practice theories and 'early STS literatures' when studying sustainable transition processes "to better understand how and why new products and technological infrastructures are acquired and how they affect practices as they are absorbed into everyday ways of living" (2012: 357), as I write earlier on page 16. The authors suggest ideas of 'scripting' and 'domestication' are of interest here: "…participants within practices often adapt and improvise their performances. As technologies are absorbed into everyday practices, new meanings and uses [of the technology] are developed"... On the other hand "the domestication of technologies is a matter of their integration within practices, which simultaneously changes the performance of those practices". It is accordingly important, they argue, to "look beyond the purchase of new products into how those products are used and embedded within existing nexuses of practices, and what the ecological impact are of those practice nexuses" (2012: 358).

4.3 User (driven) innovation theory

Break with manufacturer-centric innovation system

The role users play in relation to innovation of the products they buy has been the subject of research for centuries (Bogers et al., 2010). However, in terms of product development and innovation, for a great part of the "manufacturer-centric innovation development system[s] that have been the mainstay of commerce for hundreds of years" (von Hippel, 2005: 1), users have mostly figured as 'the consumer side' or 'the market'. In marketing and management literature the agency of consumers has resided in choice-making about what to buy. Their role in innovation has been to figure in segmentations and surveys to provide input to manufacturers so these were better able to develop and market products that meet customers' needs (Bogers et al., 2010: 858). Hence, the mainstream contention in the field of marketing and management literature – and in many other literary traditions – has until recently been that designers and engineers in companies develop products for consumers who are 'passive recipients' (von Hippel et al., 2011). The 'linear model of innovation', which this also represents has in other words been "the norm in textbooks up until the 1980's" (Hyysalo et al., 2007: 120). However, as emphasised in the other literatures this PhD project draws on, consumers have never been passive recipients, and researchers in marketing literature are also breaking with the mainstream contention – although they represent quite a different (ontological) perspective. For the last 30 years they have worked very hard to show that the 'passive user' innovation paradigm has been 'fundamentally flawed' and that "consumers are themselves a major source of product innovations" (Von Hippel et al., 2011: 27).

From a strategic perspective, users can be a source of innovation on several levels. As written in the introduction, over the last 10 years the interest in 'user-oriented innovation' has grown tremendously both in business, academia and innovation policy – notably in Denmark – and tactical interest in involving users in product development has come to include many more academic traditions beyond market research, such as science and technology studies (STS), anthropology, sociology and design studies. In general terms, user-oriented innovation is characterised by the active involvement of users in the design and production of a new product or service. In Denmark, user-oriented innovation was actively put on the political agenda when a large programme for 'user-driven innovation' was launched in 2007. The background for this political commitment was among other things based on a report from 2003, which emphasised that user-involvement could enhance the value of Danish products, since we could not compete with other countries on 'price-driven' or 'technology-driven' innovation (Rosted, 2003). More specifically, in a Danish policy context, three conceptions of the user were articulated in relation to the 'user-driven innovation' programme activities (Elgaard Jensen, 2012), although in practice many innovation projects involve a combination of these user involvement approaches. One approach includes thorough anthropological field studies among users to identify not only stated needs, like traditional marketing research, but also 'unacknowledged' or 'future' needs and desires as well as use practices – in short, to generate a more "in-depth and up-to-date understanding of users' needs" (Elgaard Jensen, 2012: 17). Another perspective is more 'design-driven' and builds upon the Scandinavian tradition of 'participatory design'. Here users are directly involved in the design phase as 'co-creators' by, for instance, developing and testing mock-ups, and other design thinking methods are used to generate novel ideas with users (Nordic Council of Ministers, 2006; Sanders & Stappers, 2008). Finally, the third approach involves 'lead users' and an idea that users can be actual inventors of products – they are 'user innovators' (Von Hippel, 2005). In this last perspective users are not only involved in innovation by being given 'a voice' that is taken into account when devising solutions (Nordic Council of Ministers, 2006), such as the first perspectives proposed, but they are actually the ones who identify and manufacture new products or who modify existing products.

Von Hippel's work on lead users and user innovators (e.g. 1986, 2005) was adopted by Danish policy makers as part of what was meant by 'user-driven innovation', but they only "emphasised the commercial potential in harnessing the creative potential of lead users" (Elgaard Jensen 2012: 18). In other words, Von Hippel's emphasis on 'democratizing innovation' and open and distributed innovation processes in user communities – e.g. where users innovate independently of any type of manufacturer to facilitate the process – were not considered interesting in relation to the user-driven innovation programme (Elgaard Jensen, 2012).

User innovators and lead users – management literature on user innovators

Eric Von Hippel was one of the first innovation management researchers to start paying attention to such 'user-innovators' in the 1970s (von Hippel, 1976), and in 1986 he introduced the notion of 'lead users' (von Hippel, 1986; von Hippel, 1988). This type of user is likely to be the very first to take up a new product, process or service prototype; they are likely to be the most innovative of users, and are also found to develop the most interesting innovations commercially (Urban & von Hippel, 1988; von Hippel et al., 2011). Lead users are important 'sources of innovation' in especially 'fast changing 'high technology' product categories' (1986) for two reasons, Von Hippel argued: Not only are they valuable for identifying 'future' consumer needs with respect to a product, they also have an incentive to devise solutions to those needs and often have the skills to do it. In other words, he defined two main characteristics of lead users:

1) Lead users face needs that will be general in a marketplace – but face them months or years before the bulk of that marketplace encounters them, and
2) Lead users are positioned to benefit significantly by obtaining a solution to those needs

The first work by Von Hippel on lead users focused mainly on 'intermediate users', such as firms (using for instance medical technology, scientific instruments or computer software) whereas later research on user-innovators has also focused on consumer–innovators (Von Hippel et al., 2011), ie. end-users. These studies have typically focused on user innovations to products related to leisure-time and sports equipment such as mountain biking (Lüthje et al., 2005), kite surfing (Tietz et al., 2005) and rodeo kayaking (Franke & Shah, 2003; see also Hyysalo, 2009; Pantzar & Shove, 2010). The research interest in consumer-innovators seems to be growing. A recent large study conducted among a representative sample of 1,173 UK consumers shows how consumers – or the household sector – generate large amounts of product innovation: 6.1 % of UK consumers innovate, and their annual product development expenditures are 1.4 times larger than the corresponding R&D expenditures of UK firms (von Hippel et al., 2012). To follow up on this, another study has explored the relative efficiency of innovation development by users compared to producers in the field of white-water kayaking. The authors found that users on aggregate were three times more efficient at developing important innovations than were producers (Hienerth et al., 2014). This has implications for producers who would like to know whether innovation development or innovation adoption is more efficient for them (Hienerth et al., 2014). Earlier empirical studies have also demonstrated that a relatively high share of both intermediate and consumer users engage in developing or modifying products. In a sample of eight empirical studies, between 10 – 40 % of the users in question innovated, depending on product type, although half of the studies were designed for other purposes and did not determine representative innovation frequencies (von Hippel, 2009: 30).

What characterises innovative users and how can they help product development?

As written above, lead users have strong incentives to innovate – but why do users chose to innovate and what characterises these individuals? How can they be used strategically to improve companies' product development? Focus in the user innovation literature revolves around such questions, which reflect two dominant interests: firstly, in identifying how lead users differ from 'non-innovative' users, what are their 'characteristics', what is the distribution of them, what factors motivate or drive them to innovate, what resources and what kind of information do they draw on to innovate and what is for instance the relative efficiency or success of user-innovations vs. producer innovations? Secondly, user innovation literature revolves around developing the lead user method and exploring how innovative users can contribute to producers' product innovation (Schuhmacher & Kuester, 2012).

Expected benefit – solutions to needs ahead of the market, entrepreneurship & fun

One important argument for why users innovate has to do with 'the expected benefit' of innovating. Von Hippel (1988) argues that the actor who expects to benefit most from innovating will be the innovator. First of all, lead users obviously benefit from solving needs early because they expect 'high rents' from *using* a solution to their very specific needs – needs that are ahead of the market (Bogers et al., 2010). Thus, the solution is tailored to their specific needs and they gain high use value from devising the solution, whereas a producer could not obtain the same monetary value by the profit they could make on the solution/innovation. Users may also expect benefit from selling their innovations and become entrepreneurs (Shah & Tripsas, 2007). Finally, users may be motivated to innovate by the mere 'process' of innovating "because of the enjoyment or learning that it brings them" (von Hippel, 2009: 33) – it simply becomes a hobby. Both of the first types of expected benefits – using and selling the innovation – are what Raasch and Von Hippel call 'output related motivations' (Raasch & von Hippel, 2013). The expected benefits from the actual *process* of innovating are termed 'innovation-process-related-motivations' and include, as said, the enjoyment of and learning from participating in the innovation development process (Raasch & von Hippel, 2013).

A lot of work has gone into developing the lead user characteristics and motivations that Von Hippel proposed in 1986, and 'lead userness' is characterised as not only 'being ahead of a trend', and driven by a 'high level of expected benefits' but also by being 'dissatisfied with current solutions': users' needs for products are shown to be very heterogeneous in many fields (von Hippel, 2009: 31), which leaves many users unsatisfied with the products available on the market. Furthermore, lead users are characterised as having among other things 'technical expertise', 'use experience' (e.g. from professional background), 'opinion leadership', 'openness to new technologies' and 'community-based resources' (Gürkan, 2014; Hyysalo et al., 2015; Schuhmacher & Kuester, 2012). Most of those users who innovate have the characteristics of lead users. Furthermore, the stronger 'lead user characteristics' a user has, the more commercially attractive their innovations tend to be (Franke et al., 2006; von Hippel, 2009: 31).

Innovation-related costs and sticky information

Other factors that determine 'the locus of innovation' – i.e. whether the innovations reside with the user and not the producer – have to do with 'innovation-related costs' (Bogers et al., 2010: 861). Users who chose to innovate avoid 'agency costs', i.e. the costs related to "a major divergence of interests between user and custom manufacturer" (Von Hippel, 2009: 32). Whereas users want to get precisely the product they need, a producer will try to lower development costs by implementing solution elements that are as broadly demanded in the market as possible or that incorporate elements they have developed already – even though this means they will develop a product that does not suit the specific needs of the user as well as it could (Von Hippel, 2009: 32).

The notion of 'sticky information' is also very important in relation to 'innovation-related costs'. Information is sticky when it is costly to move from the site it was generated to other sites (Ogawa, 1998; von Hippel, 1994). Much user-need- and use-context information (Von Hippel, 2009) is very sticky – it is tacit and difficult for producers to obtain from users, who naturally have cheap access to this information from their own experience. On the other hand, technical information about how to solve a problem, which often resides with the manufacturers, can also be sticky. The more 'sticky' the user-need and use-context information is, the more likely users are to innovate compared to manufacturers. And the more sticky solution information held by the producer is, the more the user tends to rely on 'local' solution knowledge, i.e. solution knowledge already in their possession (Lüthje et al., 2005), which fits the "economic incentives operating on users" (Lüthje et al., 2005: 951). This has the implication that users often develop products that are functionally novel – their innovations are radically new compared to ordinary producers. Producers on the other hand will also tend to rely on need and use-context information already 'in stock' (von Hippel, 2009: 33) and develop products that are improvements to well-known needs, but which require a rich understanding of solution information (von Hippel, 2009: 33).

Strategic use of lead users

From early on, Von Hippel argued for the strategic use of the lead user (Von Hippel 1986, Urban & Von Hippel, 1988) to "serve as a need-forecasting laboratory for marketing research" and "provide valuable new product concept and design data to enquiring manufacturers" (Von Hippel 1988: 107). Furthermore, Urban & Von Hippel (1988) suggested a four-step process through which lead users could be incorporated into marketing research. In step one, emerging trends and market needs for a product area are identified; in step 2, a lead user group that is 'at the leading edge of the trend being studied' is identified; in step 3, lead users are interviewed to gain insights about emerging needs and to provide input to concept development, which could also include for example 'creative group sessions' (Urban & Von Hippel, 1988: 571), i.e. a workshop process involving both selected lead users and 'company personnel' (Churchill et al., 2009). In step 4, the new concept is tested among 'ordinary' users.

Later, Von Hippel and his colleagues have further developed the 'lead user method' and developed other approaches to 'tap into' (Elgaard Jensen, 2012: 18) the creativity of users such as the concept of 'user toolkits for innovation' (von Hippel, 2001). Through this method, manufacturers supply users with specific tools that support them in developing and testing new products via iterative trial-and-error. In this way, the company reduces costs related to retrieving need-information from the users, which is 'sticky' (von Hippel, 1994) – or difficult to 'transfer' from user to producer, as described above. Moreover, it increases the volume of innovations from users by making it cheaper and easier for users to innovate – and it can steer innovation in directions that suits the concurrent production apparatus of the company (Von Hippel 2001, 2005).

Several large companies such as 3M, HILTI and Johnson & Johnson (Lüthje & Herstatt, 2004) have used lead user methods in innovation projects and the method has proven to result in very commercially attractive new 'breakthrough' products. In the case of lead user method development and use at the Medical-Surgical division of 3M, it was found that the lead user approach resulted in annual projected sales that were more than eight times higher than with traditional methods (Lilien et al., 2002). Such results underline the finding that the more lead user characteristics a user-innovator 'possesses', the greater the commercial attractiveness of the innovation.

Democratizing innovation

Von Hippel's research on user innovators has also focused on the increasingly democratized nature of innovation (Von Hippel, 2005) – and on the expanding possibilities that improvements in computer and internet technologies or new technologies such as 3D printers that make user-prototyping easier provide for 'setting the user free' from manufacturers (von Hippel et al., 2011). End user communities working on open and distributed software innovations through the internet are an obvious example of this phenomenon. User innovations tend to be widely distributed rather than concentrated among a few very innovative users. Therefore, user-innovators often find it fruitful to get together – either by 'direct, informal user-to-user-cooperation' or in communities – to 'leverage their efforts' (Von Hippel 2009: 35) by freely revealing their innovations, i.e. they offer 'freely revealed innovation commons' (Von Hippel, 2005: 95). It has been demonstrated how companies can find such user-communities and work with them by, for instance, facilitating platforms or providing toolkits to help them develop products.

Existing research on user innovativeness and the energy system

As I wrote above, user innovations have mostly been explored in relation to industry products such as scientific instruments and in relation to consumer products related to sports and leisure. Energy technologies have gained very little attention in lead user literature although the issue of innovative users has recently been explored in relation to, for instance, heat pumps and other sustainable home energy technologies, including smart grid applications (see, for example, Heiskanen & Matschoss, 2012; Hyysalo et al., 2013a; Hyysalo et al., 2013b). Other studies have demonstrated that 'end-users' in the energy system are indeed innovative by exploring how active citizens and grass-roots have participated in developing, for instance, biomass heating systems, solar collectors, wind turbines and eco-houses (e.g. Hargreaves et al., 2013; Hielscher et al., 2013; Jørgensen & Karnøe, 1995; Ornetzeder & Rohracher, 2006; Seyfang & Smith, 2007; Smith et al., 2013), and yet other studies have explored the variety of more or less 'active' roles households can have in 'greening the grid' (van Vliet, 2002; Walker & Cass, 2007) and pointed to the institutional reconfigurations needed in relation to consumer-producer relations and a break with 'old' notions of the 'demand side' (Wolsink, 2012).

An obvious reason for why lead user literature has not dealt with innovations to different aspects of the energy system – such as networked electricity systems – could be that a large part of this system is the property of the distribution system operators and moreover downright dangerous to 'fiddle with'. Accordingly, regulations concerning safety, for instance, complicate the ability of users making changes to the system[ii]. However, actual user-innovations do in fact happen, albeit most likely quite rarely. Clarification is perhaps also needed in relation to what constitutes 'the system', i.e. what is part of the system and what is not – is a smart meter (AMI) 'more' part of the system than an 'eFlex power node' or an in-home display/ a smart energy monitor? Several of the pioneer users in the eFlex study, for instance, displayed 'lead user characteristics' and several of them made actual innovations to the smart home energy management equipment as I discuss in paper 3. One of the reasons why they could in fact make innovations in this area was that they were electricians or engineers and therefore had a lot of 'technical expertise in stock' (which would count as a 'lead user characteristic'). These are of course examples of innovations to a 'home-bound' system of networked appliances, which are connected to the 'big system' and not innovations 'directly' to the electricity network. However, as the story of the 'wind turbine grid hacker' (Karnøe, in progress) demonstrates, such examples do also exist. This is the story of how the carpenter Riisager in 1972 "installed the first small 15 kw wind turbine in his garden using a transformed gear box from an old military tank" (Karnøe, in progress: 14). When the son of an engineer who had also taken part in developing another 'early type' wind turbine passed the garden, he suggested to Riisager that he should use an 'asynchronous motor' like the one his father and his father's colleague had designed for their wind turbine. This would "make it easier to connect with the grid and would allow the surplus energy from the wind turbine production to be used" (Karnøe, in progress: 14). This led Riisager to change his design and, "without asking for permission from the utilities, [he] hacked the wind turbine to the electricity grid by means of the electricity outlet to his washing machine" (Karnøe, in progress: 14).

User innovations or domestication?

As I wrote above, Heiskanen & Matchoss (2012) and Hyysalo et al. (2013) have explored user innovations in relation to smart grid applications and heat pumps by drawing on (among other things) a lead user theory perspective, and it could be interesting to continue the focus on users' innovative role for other aspects of the energy system. Also Juntunen (2014) has, as mentioned, made interesting observations concerning how householders modify and domesticate decentralized renewable energy technologies to make them fit into the local context. According to Juntunen (2014), his cases "show how users employ micro-innovation, adaptations, and different types of configurations to increase usability of the system, ease of use, and comfort" (2014: 8). I would characterise some of the modifications in Juntunen's

[ii] Thank you to Eva Heiskanen and an anonymous reviewer for pointing this out.

cases as innovations, but the lead user literature seems to have a rather more restricted view on this matter. Interesting questions thus arise concerning issues such as what constitutes an 'innovation' in the user-innovation literature, and when are we 'merely' talking about a 'modification', 'a domesticated technology', a domestication process that is very 'innovative' or a 'micro-innovation'? What about the de- and re-configurations, are they 'innovations in practice'? The third paper represents a critique of the – in my view – somewhat too teleological and individualistic conception of 'innovation' that lead user/ user innovation literature represents. Moreover, the practices related to the field of Do-It-Yourself and the notion of 'the craft consumer'[iii] (Campbell, 2005; see also Watson & Shove, 2008) are obviously also interesting to explore in relation to a discussion of the more innovative role that 'users' or 'consumers' can have in terms of altering products 'to make them fit' to their local context, although these literatures have not been elaborated on at any depth in the present thesis.

4.4 Actor-network theory

The final theoretical perspective I want to introduce is actor-network theory (ANT). However, quite an extensive amount of work has been done in this field and the literature has come to encompass different 'threads' and discussions. Accordingly, apart from my review of Marres (2012) at the end of this section, I will focus mostly on the early work and the vocabulary that was developed in the 1980s, which, however, still "works today as a widely used and acknowledged perspective in the social sciences, particular appropriate for the study of complex and controversial situations" (Muniesa, 2015: 8).

In the beginning of the 1980s, Michel Callon started working on a 'sociology of translation' (Callon, 1980; Callon, 1986; Callon, 1987), which was, however, described by his colleagues as an 'actor-network approach' (in the introduction to Bijker et al., 1987) and "in a somewhat path-dependent way, it was the notion of "actor-network theory" that prevailed in Anglophone academic circles" (Muniesa, 2015: 2). As I write in paper 4, ANT deals with issues of agency, controversies and power in the development of technological systems and scientific facts (Callon & Latour, 1981; Callon, 1986). From this perspective it is the *relations* between entities such as artefacts, "facts" and human identities that take centre stage – the entities only have existence through these relations (Karnøe, in progress). A central tenet in ANT is that of 'generalized agency', i.e. an insistence on 'non-human agency' (Latour, 1992). Moreover, a specific focus in this ontology is on the translation process, i.e. "the capacity of certain actors to get other actors – whether they be human beings, institutions or natural entities – to comply with them", which "depends upon a complex web of interrelations in which Society and Nature are intertwined" (Callon, 1986: 201). Such processes often entail struggles and resistances to be 'enrolled' in another actors 'action program', i.e. anti-programs are formed. Thus, during controversies over scientific 'facts' and technological development, for instance, "the intervening actors develop contradictory arguments and points of view which lead them to propose different versions of the social and natural worlds" (Callon, 1986: 199-200). An actor grows stronger the more "bodies, materials, discourses, techniques, feelings, laws, organisations" can be translated and enrolled in their network and the more "relations he or she can put in… black boxes" (Callon & Latour, 1981: 284). Thus,

[iii] Again, I owe thanks to Eva Heiskanen and an anonymous reviewer for drawing my attention to the craft consumer. Moreover, the reviewer suggested that DIY literature including work on the craft consumer and some of the domestication theory literature such as Aune (1996), which describe a very innovative type of user, could advance domestication literature towards a more active type of user portrait and does from the reviewers point of view in fact describe user categories and activities that fall between 'domestication' and activities of lead users.

the more durable and 'unquestioned' the relations and 'facts' are, the more the network develops into a macro-actor.

Material-semiotics, scripts and translation

John Law describes ANT as "a disparate family of material-semiotic tools, sensibilities and methods of analysis that treat everything in the social and natural worlds as a continuously generated effect of the webs of relations within which they are located" (2009: 141). He also emphasises that ANT is, in fact, not a theory; rather the approach "tells stories about "how" relations assemble or don't" and is better understood as "a toolkit for telling interesting stories about, and interfering in, those relations" (2009: 141-142). In a very basic sense, "it is a sensibility to the messy practices of relationality and materiality of the world" and "[a]long with this sensibility comes a wariness of the large-scale claims common in social theory: these usually seem too simple" (2009: 142). In a way ANT thus has the aim – just like practice theories for instance – of dissolving the classic dualisms between micro and macro analysis or agency and structure. However, instead of just demonstrating the artificial nature of these dualisms, ANT provides analytical tools to show how they are constructed. Moreover, like practice theories, ANT underlines how "'society' is an ongoing achievement" (Callon, 2001: 62) of relation- and network-building into heterogeneous assemblages. In Callon's (2001) words, "ANT is an attempt to provide analytical tools for explaining the very process by which society is constantly reconfigured. What distinguishes it from other constructivist approaches is its explanation of society in the making, in which science and technology play a key part" (2001: 62).

The material-semiotic approach of ANT implies a focus on material devices, and the notion of a 'script' (Akrich, 1992), for instance, demonstrates how a program of action can be inscribed into a material artifact. Such scripts can be part of translation processes, which "stands indeed as the crucial vehicle for the material semiotic approach of ANT" (Muniesa, 2015: 6). As written above, translation is an important element in the 'formation' of macro-actors.

Four moments of translation

The translation process is characterised by four 'moments', through which an actor tries to impose its will and "definition of the situation" on to another actor (Callon, 1986): these moments of translation are *problematisation, interessement, enrolment* and *mobilisation.* Callon developed these 'moments' by drawing on a case of a scientific and economic controversy over the decline of scallops in St. Brieuc Bay and the attempts by three marine biologists to develop a conservation strategy – the object of the study is thus to examine "the constitution of a 'scientific knowledge' that occurred during the 1970's" (1986: 202).

During *problematisation*, the researchers defined certain roles and interests of the involved actors: The fishermen have economic interests in the restocking of the bay with shell fish; the scientific colleagues are interested in advancing knowledge in this field through the proposed methods, and the scallops will 'behave' in a certain way. The researchers also "establish themselves as an obligatory passage point in the network of relationships they were building… which renders them indispensible in the network" (1986: 204). This means that they also establish the links between the actors: they show that it is in the interests of the actors to support their research programme and that "their alliance around this question can benefit each of them" (1986: 206). Thus, in this double-move, during this problematisation, a system of alliances or associations between entities is defined. The actors' identity is defined along with 'what they want' and what alliances they need to form to make it happen. The moment of *interessement* is about 'cornering the entities to be enrolled' (1986: 211) through various devices, such as texts, conversations or the 'towlines' which scallop larvae are supposed to anchor to and grow from according to the scientists. In other words, interessement devices "extend and materialize the hypothesis made by the researchers" (1986: 209) and help break the links to competing problematisations made by other actors. *Enrolment* is the moment where interessement is successful. "To describe enrolment is thus to describe the group of multilateral negotiations, trials of strength and tricks that accompany the interessements and enable them to succeed" (1986: 211). Thus, enrolment of the scallops would entail that they did in fact anchor themselves to the towlines, which was a basic presumption of the researchers. Finally, *mobilisation* is about talking on behalf of others, which also involves silencing "those in whose name we speak" (1986: 216). In this case, "both fishermen and the scallops end up being represented by the three researchers who speak and act in their name" (1986: 216).

Moreover, concerning the scientific community, a cascade of intermediaries reduces the number of representative parties little by little, and the few colleagues who attend conferences, for instance, speak in the name of all the researchers involved. "Once the transaction is successfully accomplished, there are three individuals who, in the name of the specialists, speak in the name of the scallops and fishermen" (1986: 216). In this way, the three researchers have become 'powerful', "they have become influential and are listened to because they have become the 'head' of several populations" (1986: 216). They have succeeded in mobilising all the actors by displacing and then reassembling them: "The scallops are transformed into larvae, the larvae into numbers, the numbers into tables and curves which represent easily transportable, reproducible, and diffusable sheets of paper" (1986: 217). The researchers can use these 'silenced actors' as ways of getting support for their program of action. The different 'populations' have been mobilized, because they participate in supporting the researchers' action program through these "interposed representatives" (i.e. numbers, papers, graphs etc.) (1986: 218). Thus, "the enrolment is transformed into active support" (1986: 218).

ANT, energy system controversies and the smart ontology

An ANT approach to exploring the smart grid imagery and its construction would be obvious in my opinion, although I have not yet come across many studies that take an ANT approach to exploring this field. However, the specific construction of a 'disengaged public' in the smart grid has been explored through an ANT perspective (Schick & Winthereik, 2013) and in terms of the energy system in general, controversies over wind energy projects have for instance also been explored in an ANT perspective (Jolivet & Heiskanen, 2010). Interestingly, Noortje Marres has discussed the ANT concept of a 'topological imagination' in relation to the case of the smart meter and digital issue mapping tools (Marres, 2012: 291). Topological ideas were introduced among ANT and feminist STS scholars as a way of articulating the fluid entanglement of technology and society and were borrowed from relativity theory in physics "where topological ideas had found an influential application, as in the idea that 'objects-in-relation' generate their own space-times" (2012: 292). The idea was that space and time were not seen as a priori categories, "and, in an indirect way, this enabled the reformulation of the theoretical question of the relation between the social and the technical" (2012: 292).

Her argument is that the two types of digital devices – smart meters and other digital energy management devices versus issue mapping tools on the web – both represent topological devices. However, whereas the first only represents a 'weak' topological device, the second represents a 'strong' version. Concerning the first case of smart meters, Marres argues that in some ways they represent a topological imagination by ‘expanding the frame on technology’ (2012: 293) or rather, they expand the frame on energy use by broadening the range of entities “considered relevant to energy use beyond the ‘strictly technical’” (294). ‘Expanding the frame on technology’ means moving away from “a restrictive focus on technology as the principal agent of innovation, and an expansion of frames of analysis to foreground socio-technical processes of ‘the ongoing, collective practices of sociomaterial configuration and reconfiguration in use’” (Suchman, 2005: 12 in Marres, 2012). In other words, smart meters “invoke topological ideas in order to bring the social and the technological together” (2012: 293). An example is for instance when smart meters feed data to energy visualisation tools on the internet and produce:

“…a real-time graph, which is marked up by users, noting things like toasters being switched on and off; the fact that it is Friday night, and the presence of teenagers in the house, or how smart they and their devices are in doing the laundry at night rather than during the day…” (293)

Thus, smart meters (and related smart home energy management equipment) highlight “the ways in which technologies are ‘alive’ with sociality” (2012: 303) – or in a practice theory perspective, they may point to how intimately connected household energy consumption is with everyday practices. This was also the point that was made in antropologerne.com’s report (antropologerne.com, 2012), when they argued that the eFlex equipment constituted a ‘missing link’ between everyday life and the electricity consumption of the house. In a way, then, such devices “highlight continuities between the social and the technical in ways that are not dissimilar to those outlined by sociologists” (2012: 293) as they include heterogeneous elements such as teenagers, toasters, laundry etc. in the “equation of energy use” (2012: 294).

However, this ‘frame expansion’ still happens within a “technologically delineated space” of ‘energy-use’ (2012: 304), which means that “they do not, in fact, ‘expand the frame’ on technology at all. Smart energy meters may be presented, in advertising and other publicity materials, as a means to broaden the range of entities considered relevant to energy use, but they do so in ways that are very limited”. These devices do, in other words, not disturb dominant conceptions of social order, for instance, “society is here defined in solidly scalar terms, a tiered system with individual consumers at one end and the national system at the other” (2012: 295). Smart meters etc. “only ‘expand the frame’ to include relatively ‘safe’ micro-entities like teenagers, and not more complicated entities like ‘carbon markets’ or ‘peak oil’” (2012: 296). Moreover, and more importantly, Marres argues, they perpetuate a deterministic understanding of the relationship between technology and social change and thus keep “the idea of technological innovation as the principal driver of change… in place… and does not challenge the ‘primacy of technology’” (2012: 96). Somewhat in line with Strengers’ 2013 argumentation concerning energy feedback and the smart ontology in general, they continue to figure as “something that enables the social but is in no way reducible to it” (2012: 296). Smart home energy management technologies can be argued to be interessement devices that among other things aim to enroll householders and other stakeholders in the action program of dominant energy system actors.

Conversely, the other case of a topological device, namely digital tools for the analysis and visualization of public controversy – like the ones taught on the ‘mapping controversies’ course mentioned earlier – has more potential to ‘expand the frame on technology’. These are digital extensions of more ‘analogue ways’ that sociologists of technology and ANT scholars have long (e.g. Callon et al., 1983) performed network and textual analysis “in order to capture the unfolding of controversies in ways that we can call ‘topological’” (2012: 299).

Controversies entail the unfolding of heterogeneous – social, technological, environmental, political, economic – concerns and thus, "where objects turn into issues, scientific, moral and social concerns turn out to be intimately related and entangled" (2012: 298). Accordingly, by considering smart meters not just as devices for frame expansions, but instead as "*objects* of frame expansions" (2012: 297), i.e. how they are topics for public controversy, it is possible to 'expand the frame on technology' in a much stronger sense. This has implications for how we imagine the relation between technological change and social change. Topological devices like web controversy mapping tools bring "into view the proliferation of contending articulations of techno-social change, and, thus, a situation in which different forms and types of change are made visible, although they cannot be assumed to be neatly aligned" (2012: 304).

Thus, unlike the smart meter itself, when it is seen as a *topological device*, controversy mapping of the smart meter (involving issues such as privacy, surveillance, fuel poverty and remotely cutting peoples' electricity etc.) enabled by digital tools has an entirely other potential for expanding the frame on technological development, i.e. it presents among other things a critique of assumptions about which 'technological path' is the 'right' one etc. This also has the effect that as "more and more entities prove to be implicated, socio-technical dynamics turn out to be much less coherent than expected" (2012: 304). Again, such a topological approach makes issues of power-relations etc. much more visible in terms of socio-technical development and will continuously 'open up smart meters' instead of perpetuating a process of 'black-boxing' them.

4.5 Ontological compatibility?

As I wrote in the introduction to the theoretical section, the theories I have been engaged with share many core concerns, and now and then in the theoretical descriptions above I have touched upon what ideas the theories share and where there can be 'cooperation' between them. In paper 3 (page 133-135) I reflect a little bit on my choice of theories and how I see them complement each other despite their different ontologies.

Domestication theory has for example inspired me to think about how the entire family take part in negotiating the creation, death or reproduction of the practices performed in the household, which for instance integrates the eFlex equipment as an important element. In relation to domestication theory, practice theory broadens the perspective on the technologies' integration into everyday life beyond how a technology is received in a home and ascribes, and is ascribed, new meanings and uses. Instead, a practice theory perspective brings attention to a wider range of practices in the home that are 'interacting' with this new artefact and on what the practices' spatial and temporal relations and structures mean for this interaction. Both of these socio-material theories, practice theory and domestication theory, on the other hand, provide the background for my discussion of 'lead userness', which I will also elaborate a little bit more on in the discussion of my papers and findings below.

However, an emerging debate, which I find very interesting and which I have not touched upon but hope to work with in the future, is concerned with the similarities and differences between actor-network theory and practice theory, and if and how they can be fruitfully 'combined'. Davide Nicolini (2012), for instance, provides some interesting hints to such an exploration in his recent book (2012), and the issue was also discussed at the conference

"Practice Theory – a New Research Agenda – and its Implications" held at Aalborg University in Copenhagen in June, 2014.

Both practice theory and actor-network theory are 'flat ontologies' or 'relational sociologies' and both "reject the idea that the world comes nicely divided into levels and factors, or that there is a fundamental distinction between micro and macro phenomena" (Nicolini, 2012: 8). Both approaches have also been somewhat criticized for completely neglecting larger macro-structures. Although 'structure' in a practice theory perspective can more or less be conceptualised as the relation or link – and the strength of the links – between practices and between their elements, some (e.g. Røpke, 2009) would argue that such "observations do not sufficiently highlight the interplay between practices and wider social systems, their institutionalized features and material infrastructures" (Røpke, 2009: 2492-93). The actor-network theory research agenda in Denmark has also been criticised for focusing too little on macro-actors and power, although some studies (e.g. Karnøe, in progress, Nyborg & Røpke, in progress) take such a focus.

Besides the shared uneasiness with 'structures' and macro-phenomena, the two approaches are 'disagreeing' on several points. Fundamentally, they have different ontological units of analysis. Actor-network theorists think in terms of associations and deny the notion of 'practices', which are considered too complex a unit – and it does not make sense to for instance consider such already existing composites as 'actors' in a network. Perhaps Nicolini's background in actor-network theory explains his rejection of the notion of 'practice-as-entities' – he would rather talk of these as 'discursive constructions' that can be inscribed in objects, for example. Moreover, as opposed to actor-network theory, practice theory also includes elements of 'meaning' and normativity, which in Nicolini's (2012) view is lacking in actor-network theory. Much more has been said and should be said concerning the two theories, where they differ and where there is basis for developing theory through an exchange of ideas. What I am interested in is, for example: how do actor-network theory and practice theory account differently for issues of power? Nicolini (2012) for instance writes, "all practices, even minute ones, constitute identities and sustain hierarchical power relationships" (2012: 234). How does this more specifically play out? And can we talk about power without talking about macro-structures?

5 Presentation and discussion of papers

In this final discussion, my aim is to discuss and answer the main research questions I presented in the introduction. Doing this I am drawing on findings and insights developed in all the four papers that are part of this thesis. Therefore, I will briefly introduce the main findings in each paper, but the reader is advised to read the papers before this discussion of the research questions. I will moreover supplement my discussion of my own work with studies that have been published after I wrote the papers in order to bring my discussion up-to-date with recent developments and ideas and bring in a new perspective on my work.

5.1 Discussion of research question 1

What role are households envisioned to have in the smart grid? What constitutes this role and how do energy system actors explore and strategically construct this role? (Papers 1 and 2)

In Paper 1, 'Energy Impacts of the smart home', Inge Røpke and I aimed to characterise what visions were at the time formulated regarding the role of households in the smart grid and regarding the functionality of the smart home. Moreover, we outlined some of the issues and controversies that were prevalent in relation to these visions of the smart grid. Secondly, we discussed whether these visions would support the dynamics that constitute a sustainable transition of the energy system.

The visions and functionalities of the smart home have been outlined above on pages 14-16 and in paper 1, but to sum up: Householders are expected to invest in heat pumps and electric cars (although this 'investment role' is generally under-illuminated, also in the present thesis), and also in smart home energy management equipment, which will help them make the 'right' consumer choices: to consume electricity in ways that suit the system, i.e. 'when the wind blows' and not in collective peaks. In the smart grid vision and in the developing design of the smart grid, householders are thus dominantly articulated as consumers who should not be bothered with the transition. Rather they should in fact experience increased comfort and convenience while system builders are merely making technologies smarter. If I have to articulate myself rather plainly, designing the smart grid and the smart home as a solution to the sustainable transition of the energy system is very much the wishful thinking of engineers and economists, which is also the point that Strengers (2013) makes.

It is often argued that "the problem with categorizing publics as consumers… is that consumers are kept passive and not engaged in infrastructure planning" (Schick & Winthereik, 2013: 90). Although the term 'prosumer' – i.e. a consumer who produces energy that covers his or her own and partly others' needs – implies a more active role for the consumers in the new system, this role is not very elaborately dealt with in the field or discussed among smart grid actors in Denmark. As discussed in the introduction, the notion 'active' is often used in the smart grid field, when the talk falls on the new 'empowered' users or consumers in the smart grid. At first glance, this may collide with my discussion of how householders are dominantly framed in a 'passive' consumer role. However, as Strengers (2013) also argues, this notion of active is connected to an active *consumer*, to *Resource Man*, who may actively *take control of his consumption* and become a dutiful partner in upholding the system. Therefore, the new active consumer departs from the old situation, where it was the system that actively had to adjust to the consumer's 'static' demands – however, he is still framed in *a consumer role*, not as someone who owns or develops part of the system, as an investor, innovator etc.

In the first paper, our argument was that these ideas that were developing about what the smart home should look like and how it should assist smart consumers in performing the smart grid should be seen from a historical perspective: the current conceptualisation and development of the smart-home-in-the-smart-grid was only the latest addition to a family of ideas that had developed over time, which related to using ICT in the home to 'augment them' and make them smarter, more convenient, safer and more entertaining. Therefore, the current ideas about enrolling households in the smart grid co-developed with these ideas – the smart-home-in-the-smart-grid became a 'melting pot' of these old and new ideas, which we argued would have negative energy impacts. Our contention was that the smart home – which was developed in the setting of these historical developments – was accordingly 'sold' to householders as something that would not just entail 'smart energy management', but also increased luxury and pleasance, as Strengers (2013) also argues. In other words, we found that system builders clearly related and framed the 'new, greener home' in relation to these previously developed ideas – in our conceptualisation they 'funwashed' the 'boring demand management' with the already emerging or developing ideas related to a 'smart digital home'. In a way, then, the smart-home-in-the-smart-grid became a Trojan Horse that could take part in supporting the unsustainable development of practices and the escalation of expectations of comfort, which can indeed have negative energy impacts.

In Paper 2, we explored how a big system builder actor investigated 'the real householders'' willingness to take on this role as 'partners' in the system with the help of smart home energy management technologies. The eFlex project represented an interesting attempt to involve users and their ideas and everyday life as a basis for developing the 'right' system that would fit their 'needs and desires'. In the smart grid field there is certainly some interest in figuring out "how to get the humans 'on board' the development" (Schick & Winthereik, 2013: 91), but this is often accompanied with uneasiness about how to engage with this 'unruly factor', which is in any case always kept at arm's length and out of 'the engine room' (see Schick & Winthereik 2013). In contrast, the eFlex project quite actively involved users in the development of the system through an open co-creation process where both users and system builders could 'rehearse the future together' (antropologerne.com, 2012).

However, despite its many interesting findings and approaches, in my view the project was still designed with a relatively narrow consumer role in mind. It didn't quite 'expand the frame on technology' (Marres, 2012), which is perhaps not surprising, since it was a consultancy job for DONG Energy. The new smart energy consumer may develop new insights about what 'belongs' to the world of electricity through the energy management equipment – new relations are forged and in some ways householders are 'let into the system' or 'invited into the engine room' – but the project does (quite naturally) not explicitly open up questions about the desirability of the development or the controversies pertaining to it (Marres, 2012). On the other hand, the eFlex project did, in my view, not play the 'funwashing card' to get the householders 'motivated to play along' to the extent that other actors in the smart grid do (which was perhaps because the project was moved from sales to distribution - see paper 2 on that point).

Furthermore, in our view, the study could have benefited from more explicit attention to social practices related to heating and transport if the main interest was in considering the 'flexibility potential' in heat pumps and electric cars. To quote Walker (2014) again, "managing the rhythmic profiles of energy demand on any significant scale means somehow managing the rhythmic patterning of the practices out of which energy demand is produced" (2014: 52). However, looking more into householders' motivations to become 'partners' with Dong Energy had, perhaps, stronger potential to create a 'desired' result because householders would quite visibly become allies then. As we discuss in paper 2, through the eFlex project, a role for the householder that fitted DONG Energy's action program was constructed with the help of 'experts' that could legitimately talk on behalf of householders: During the co-creation process a householder emerged who was interested in peak shaving and in becoming partners with DONG Energy. In developing this point, we introduced the concept of the 'aligned user'[iv] to the field of user-oriented innovation to supplement notions of, for example, the represented user, the projected user and the real user (Schot & de la Bruheze, 2003).

It is important to say, however, that I am quite certain that this 'aligned user' was never the deliberate strategy of DONG Energy. Arguably, they were not very attentive to their own role in creating a certain result, but rather believed that the 'experts on humans', i.e. antropologerne.com, could lift the curtain and reveal 'the truth' about the householders and thus help them 'design with the users and their inner desires'. In their view, these users would ultimately benefit from the project: If the householders helped DE distribution with avoiding peaks (which arise from the electric cars and heat pumps that energy system stakeholders 'tell' them to buy) they would also reduce the public investments DE argued would have to be made in the distribution net infrastructure. However, there were a lot of assumptions in the project about the 'path' of the energy transition and the householders' role in it, which the householders were not 'let in on'. Again, a user study could also have focused on exploring what other types of arrangements and configurations of the system could support the politically agreed goal of moving towards a system that is 100% fossil free. Instead, DONG Energy's understanding of what the right solution is to current sustainable transition issues permeated the project, and this of course had consequences for 'what questions were asked and sought answered by the users'. However, it is a policy goal to implement much more wind energy in the system in a 'centralised manner', and therefore a user study of the latter 'alternative type' would not make much sense for DONG Energy to do.

This aligned user was, of course, not an absolutely 'artificial' construct. Undeniably, many of the householders found the project and 'flexible consumption' very meaningful and sensible, and something that they wanted to contribute to. Moreover, as antropologerne.com very interestingly pointed out, an important result from the co-creation project was not just this construction of the consumer, but also the learning that took place in DONG Energy about their 'unruly loads'. Noted in parentheses, it could have been interesting to discuss if and how findings concerning for instance 'sensibility' would differ between cultures and nationalities where trust in collective supply systems – or expectations of undisrupted and secure supply or of comfort, among many other things – varies greatly.

In conclusion, both papers illustrate a techno-economic focus in the smart grid arena and an idea that householders, when considered, are consumers who should be motivated to assign control to technology or use technology to take control of consumption to participate in the functioning of the system. They are 'bumps on the road' that need to be overcome in order to be able to roll out the new system. They have an individual responsibility and their actions are enabled and mediated by smart home equipment, which will help them take on the role of 'partners' in the system. Their actions are thus enabled by the technology and driven by

[iv] The idea of the aligned user as a tactical move in relation to a wider strategic process of system building differs from Akrich's (1995) discussion on alignment of user positions (see note in Nyborg & Røpke, 2013: 668)

various ‘motivational factors’ – and the latter is in most smart grid projects expected to be monetary incentives, although the eFlex project specifically emphasised that other motivations could be at play. Such projects as the eFlex project are very performative in the sense that they strategically construct an image of a consumer who wants the system that is being designed.

However, this vision of the dutiful smart home inhabitant and the constructed aligned user is not the whole story. As paper 3 points out, householders are also many other things, and they certainly have various anti-programs, which may not end up in interessement devices such as a user study report, but these ‘overflows’ nonetheless also have agency. On that note, I will carry on to discuss my second research question.

5.2 Discussion of research question 2

What roles do households have in the energy system, other than being merely ‘consumers’? (Papers 3 and 4)

In this PhD project it would, perhaps, have seemed obvious to draw more on literatures that explore the role of civil society in sustainable transitions or grass roots innovations, which I have referred to earlier, since I aim to provide insights into the role households have in a sustainable transition of the energy system and to provide alternatives to the consumer portrait. However, as my specific case was ‘the smart grid’, and as I ended up doing fieldwork in the eFlex project, it seemed that other literatures were better suited to an exploration of the experiences and emerging ideas that developed while I was in the field. Notably my experiences from the eFlex households inspired me to look towards ‘lead user’ literature, both because it enabled an articulation and discussion of some interesting phenomena I took home, but also because I saw interesting examples in the field of how this user innovation literature could be discussed and critiqued from a completely different perspective.

In my third paper, I aimed to bring attention to the many ways in which householders are definitely not always ‘aligned’ with the system and do not necessarily fit into the above visions – that the framing of them as ‘consumers’ is too narrow, and that they for instance also have a striking desire to innovate on and develop their own systems. The eFlex householders’ many innovative activities described in paper 3 support this point, e.g. Benny’s ‘cheating’ with the heat pump optimisations or Jens’ self-made electric hob that allowed him to ‘optimise’ his heat pump more often than DONG Energy had planned. There are of course several other examples from the field that could support this argument, which were not included in the paper. The introduction of the social media platform PODIO in the eFlex project, for instance, provides an interesting case in point in relation to the issue of ‘disobedient’ householders – or householders that do not want to take on the role that is ‘assigned’ to them.

As written earlier, PODIO had several functions in the eFlex project and one of them was to provide a communication channel between the householders and antropologerne.com, who could continuously explore the householders’ ideas and thoughts related to energy and the energy management equipment. One of their methods was the ‘el’sk’ thread mentioned previously, where the householders were encouraged to take part in building “an alternative electricity universe” by, for instance, sharing their everyday experiences with the equipment and providing an alternative language to the technical language of DONG Energy. They could, for example, write on PODIO what they called the 'power nodes' – for example 'thingies', 'devices' or whatever. However, as it turned out, the householders did not really comply with this idea despite intense effort from antropologerne.com. Instead they used PODIO much more as a place where detailed calculations of economic savings or notably the technicalities of the GWR equipment and electric vehicles or heat pumps were discussed among the most technically interested participants. As written in paper 3, they also shared tips and tricks concerning how to modify the equipment to their needs – Jens for example 'freely revealed' his homemade electrical hob that allowed him to optimise his heat pump more often. Many of the posts on PODIO were also often directed to DONG Energy and concerned with the functioning of the equipment. Therefore, DONG Energy took over the moderator role and the daily dialogue with the users on PODIO in the autumn of 2011 – and accordingly placed more of the technical support on PODIO instead of on email or telephone.

Other obvious examples of householders that depart from the simple portrait of the 'hedonistic comfort-seeking consumer in the energy system' in the smart grid empirical field are obviously 'the wind turbine grid hacker' mentioned previously or the 'self-builders with zest and pioneer spirit' that are discussed in paper 4. A final example relates to the DREAM project, which I only mention in paper 4, page 31. The DREAM project ("Danish Renewable Energy Aligned Markets"), which the Danish Technological Institute for instance is involved in, explored the possibility of smart grid technology rollout in villages in areas outside collective supply systems. The project started out with an anthropological field study in two villages to create knowledge about the "socio-cultural conditions" that play a role for such imagined smart grid 'roll-out' and that should provide input to the further R&D work in the DREAM project and for future business models (Svanborg & Aarup, 2014). What the anthropologists found was that not only individualised economic considerations played a role for 'people's actions' and for the fate of heat pumps in these local societies, but that:

- local community culture and social orientation were important
- a pronounced do-it-yourself culture existed in both villages
- self-control and freedom were important
- the functionality of the house was more important than aesthetics, and that renovation often was done for practical reasons and not for 'beautification'
- 'superfluous consumption' was not prestigious and that it is important to make 'a good deal'
- heat pumps and electric cars are black-boxed technologies that people cannot 'fiddle with', as they are used to with their other heating systems and gasoline cars

There are several points to take from this and I will elaborate on some of their findings below.

Community orientation

Firstly, this study emphasises how it is not just isolated individuals – or individual households – and their relation with the energy system that matters, which other literature on civil society also emphasises (e.g. Seyfang et al., 2013). 'The smart grid world' consists of a smart electricity system, where 'smart homes' are positioned as multiple separated islands or 'nodes' at the outskirts of the system and there is only an 'individual household-electricity system' relation. On the contrary, the anthropologists from the DREAM project found that people were strongly oriented towards the local community and context they were part of, and they argued that new smart grid strategies should rather talk to the community as a unity than approach people as isolated individuals. As found in other Danish studies on heat pumps (Epinion, 2010; Publikum Kommunikation & inVirke, 2010), people often trust local advice and experience more than information from the internet, for example. In the DREAM case, this was for example reflected in the fact that in one village there were few heat pumps but many pellet burners, whereas in the other village, there were many heat pumps and few pellet burners. It also means a lot what the local installer prefers and would recommend – if he or she is 'a pellet burner' or heat pump proponent.

Do it-yourself, freedom and self-control

The anthropologists also found that there was a very distinct do-it-yourself culture in both villages. As they write, "most people do not make use of craftsmen, but take care of building project themselves with the help of family, neighbors or friends. There is often a bigger degree of trust in one's own work, and there is a lot of drive and agency among the citizens" (Svanborg & Aarup, 2014: 12). This DIY culture, with its concomitant building up of skills, local sharing of tips and tricks and stock of physical 'tools', also means that the households have and prefer different and tailor-made energy supply solutions. The citizens consider these solutions more 'controllable' and flexible to their needs and local possibilities for getting 'a good deal' on fuel, for instance. A solution with an oil boiler, which can be supplied with biomass fuel and a solar panel, entails a sense of control and freedom, because they can among other things negotiate the price of wood or other fuels.

Anti-superfluous consumption and making a good deal

The above findings also relate to a point about 'thrift'. As stated above, it was important to the house owners that they could make a good deal concerning their energy source. With electricity, for instance, they had no control over the price, whereas if they had a biomass burner etc. they could collect the wood themselves or get it for a cheap price from a friend or neighbour or another local actor. One interviewee for instance explains how he could get free wood from the local factory if he just came and collected it himself. Thus, the villagers would not necessarily prefer a high-tech, low maintenance heating system, which provides the highest level of comfort. Obviously, people have many different rationales in relation to the heating system and what is important to them.

Black-boxed smart grid technologies

Assigning control to smart grid technologies that work silently in the background of everyday life does not seem like a solution in such cultures. These new technologies are too black-boxed and automated: "Technologies such as the heat pump and electric car are in these areas challenged by being too obscure and different from the mechanical technologies the citizens are used to" (Svanborg & Aarup, 2014: 12). Also electric cars are not possible to be fixed by yourself to the extent that an old gasoline car can. "Many appreciate being able to 'fiddle' with making it work and can with the hybrid solutions turn on different buttons depending on price, weather or materials" (2014: 16). Finally, to conclude this discussion of the need for exploring other roles than the 'consumer role': By moving focus away from *individuals* towards *practices* and *relations* when considering 'innovations' in paper 3, I have also addressed the conceptualisation of individuals having static roles 'in' the system, which is too functionalistic a perspective. Instead I attempted to illustrate that subject positions are fluid; they constantly change and are negotiated, and they are formed by the practices we carry. Through these practices we perform the system; we do not have a role *in* it. In this way, households of course play a role *for* the development of the system.

Innovative users, domestic practices & academic writing practices

For the final bit of my discussion of alternatives to the consumer role, I would just like to present a brief reflection on my work with paper 3 and my exploration of 'innovative households'. Besides presenting findings that illustrated the need for recognising householders as other than merely 'consumers', in paper 3 I also aimed to make a point in relation to the ongoing research about 'lead users' and its strong focus on individual users and products, and on inherent 'lead user characteristics'. Instead, by shedding light on 'what energy is for' (Shove & Walker, 2014) and on the dynamics of domestic practices and how these interact with technologies and products, I argued that innovativeness is a collective, contextual and complicated affair, and that the 'innovations' that were made in the households were not merely the result of an individual with the right 'lead user characteristics'. Rather, I unfolded how a range of domestic actors and practices had importance for lead users' innovative activities.

Arguably, this contribution to the on-going discussion concerning 'lead userness' in the lead user research community falls somewhat 'outside the paradigm'. In other words, the insights I present in my third paper do not address the questions or 'gaps' that this community believe are important to address in terms of knowledge and theory-building. Rather, it addresses a 'gap' *I* believe should be addressed. I came to think of this as one of my reviewers stated that he or she didn't clearly see where my contribution to the lead user literature was. Of course, the 'filling a gap' verbalisation is mostly a 'communicative move' in order for you to be able to argue for why your research is interesting. Therefore, if your argument is 'good enough', you should in principle always be able to 'sell' your idea as a contribution to theoretical or empirical knowledge in the field. But if you always have to write up against an existing debate in a range of 'typical journals' that set out or suggests specific gaps to be 'filled', then it can be difficult to argue for entirely new perspectives, I would argue. Thus, in my view, this sort of academic journal writing practice does not really address the issue of *who defines what the gap is and what is valuable knowledge*. Nonetheless, I believe comments or contributions to a field from an 'outsider' to a research community can be useful in terms of exploring new ways of thinking about the field. The reviewer – who may arguably be open to other approaches than the ones that are usually sought in the lead user research community, since the paper was submitted to S&TS Journal – did, however, point to the value in contributing a qualitative study in this domain, as I do.

However, I also believe my third paper contributes to knowledge-building besides 'making a comment' to the lead user research community. First of all, as written above, by having a focus on 'what energy is for' and by providing a much-sought detailed and qualitative empirical account of how smart grid technologies are 'absorbed into everyday ways of living'. Moreover, by giving an account of how 'flexible demand' is contingent on rhythms of practices and how these are connected in bundles and are interacting with larger structures outside the home. Secondly, it provides an example of how domestication theory –in my view – can be 'invigorated' by combining it with a practice theory perspective. Finally, it contributes somewhat to the practice theory community by illustrating how 'sociality' in the space of the home has an importance for what practices are performed and developed, and how 'carriers of practices' negotiate the meaningfulness of different practices and how they can fit into a 'moral economy of the household'. I will discuss these things further below.

5.3 Discussion of research question 3

How do families domesticate smart home energy management technologies and how do the technologies interact with the continuous changes of domestic practices? (Papers 2 and 3)

By participating in the eFlex project, I got insights into "the ways in which the day-to-day reproduction of social practices might adapt to interventions which aim to re-constitute the grid" (Powells et al., 2014: 51). The fieldwork among the eFlex families revealed that the smart home energy management technologies and the heat pumps interacted with a range of practices in the home "as varied as cooking, laundry, dinner and dishwashing, airing-out, watching TV, playing computer, communicating with friends, brewing tea and coffee, commuting to work, lighting a fire in the fireplace, bed-time rituals, 'leisure/passing time' practices, 'parenting', 'walking the dog', [caring for living room plants], theft protection, heat comfort, hobbies and many more" (Nyborg, in progress: 11).

Thus, the equipment became 'absorbed' into certain practices, but at the same time it also became part of developing new provisional practices that were being negotiated and trialled in the home. For example, the equipment became integrated in Peter & Charlotte's family-project practices, but the technologies also became part of new emerging practices, for instance practices of routinely checking the eFlex portal at night before going to bed to survey certain devices' electricity consumption, check the next 24 hours' prices or turn off all unnecessary consumption. As I moreover write in paper 3, the eFlex smart home energy management equipment was domesticated into unique 'moral economies' of the households, which were constituted and configured by certain practices that were performed by the household members. These moral economies thus had an influence on what the equipment was actually used for and what practices it co-developed with. As I write on page 5 in paper 3, "domestication is thus the way each household finds its own unique way of integrating the equipment as an element in the performance of a range of its everyday practices, which accordingly may develop and diversify the practices (Røpke et al., 2010) or lead to the creation of entirely new ones" (Nyborg, in progress: 5).

Generally, domestication of the eFlex equipment led to both intended and non-intended uses, as evident from above, where it both led to reflections on and new meaning ascriptions to electricity (and heat) as a 'scarce' resource – quite similar to Strengers' (2013) points in relation to dynamic pricing and micro-generation – but also to surveying and control of family members, etc. Smart home energy management technologies present an interesting case to explore both from a practice theory and a domestication theory perspective, which are approaches that both may illuminate several issues that complicate their 'uptake'. First of all, because such energy management technologies are 'complex' technologies, since they are 'doubly articulated' – they are both physical entities (e.g. 'ugly' power nodes) as well as 'messages' (e.g. information on dynamic prices and meanings or messages related to 'flexibility' and energy). Secondly, because they interact with a range of domestic practices, since electricity (and hence the equipment) is a ubiquitous element in many practices performed by all members of the household. By drawing on both practice theory and domestication theory to analyse the introduction of the eFlex equipment into households, I have attempted to explore some of the rather 'unknown territory' Strengers (2013) mentions in her book about the role that 'immaterial materials' – such as energy – as well as infrastructures and smart home technologies play in practice.

Domestication, conflicts and negotiations

What I started discussing in relation to research question two above is how the eFlex fieldwork illustrated that in some cases domestication of energy technologies involved actual user amendments to make the 'technologies fit' (Juntunen, 2014). In paper 3, I argue furthermore that what it is these technologies are going to 'fit *to*' is a contested and negotiated domain. Because energy is an ubiquitous element in probably the majority of domestic practices performed by all members of the household, energy management technologies intrude on many domestic practices in a way that may not be obvious – or agreed upon in the household and 'in line' with the moral economy of the household. Moreover, 'demand flexibility' confers a disruption of the daily rhythm and coordination of practices and projects in the household. In other words, as "energy consumption happens in the course of performing 'time-and-place bounded' practices, which are often tightly coordinated in everyday life, experimentation with *flexibility* also resulted in conflicts, because other family members' practices were disrupted" (Nyborg, in progress: 14).

What I also point to in papers 2 and 3 is that a source of conflict in the domestication of the eFlex equipment in particular was that the equipment's affordances did not support a 'collective' domestication. However, flexible electricity consumption in a 'smart home' is indeed a collective achievement and not just a question of Resource Man's desire and ability to 'take control of his consumption' via a smart energy monitor. In paper 3, one of my arguments was that it is not just important to focus on 'a user' and his innovations, but also pay attention to "his or her 'fellow' carriers and the continuous development of the practice the 'innovation' is part of – all carriers of practices are in a sense innovators as well as producers and consumers at the same time" (Nyborg, in progress: 16). The appropriation of the eFlex equipment also conflicted with practices and structures 'outside' the home, which the eFlex participant Martin – who owns an electric car – provides an example of. His ability "to be flexible with charging his car also depended on his working hours and congestion patterns; with his type of battery, if he were to take full advantage of the cheapest electricity prices in the early morning hours, he would have to postpone the time he left in the morning. Conversely, that meant he would run into another problem of travelling peaks and congestion" (Nyborg, in progress: 14).

Power struggles & the home as a 'practice innovation junction'

In the following sections I will reflect on issues that I have not discussed very explicitly in my papers, but which I have recently started thinking about as I wrote the present introduction to the papers. These issues are concerned with connections between practices and their collaboration and competition (see Shove et al., 2012) in the household. In my papers I have mostly focused on how practices related to domestic activities connect in bundles, for example. However, my impression is that the dynamics characterising the connection between practices in a domestic 'social' setting and the conflicts and negotiations between carriers of practices over, for instance, getting to perform their practices in this setting are not discussed very much in the practice theory literature.

So far in this thesis, I have discussed a little bit how practices in the home are co-developing with the household's 'moral economy', but what I want to reflect more on is how practices are also performed in the *space* of the home. A concept that may be useful for such a venture could be Shove et al.'s, (2012) discussion of office spaces as 'innovation junctions' (drawing on De Wit et al., 2002), which "underline the importance of spatial and material arrangements for the re-structuring of …practice" (2012: 85). According to Shove et al. (2012), "sites like offices and homes can have emergent consequences for the trajectories of individual practices and hence for the collection of practices that are, and that are not, enacted in such environments" (Shove et al., 2012: 85). Such spaces facilitate 'generic linkages' between elements and practices and thus favour "some but not other forms of association", and therefore "places are more than contexts or settings in which performances are enacted. In certain situations, co-location results in new hybrid forms: novel practices emerge" (2012: 124). Thus, such distinct spaces as homes can function as 'innovation junctions' because they support co-location between practices that may 'cross-fertilize' (2012: 86).

However, my argument is that innovations in practice in this way may not only arise as a result of 'collaboration' or co-dependence between practices, but also because of competition among them, which enforces a change in practices so these can 'co-exist'. In other words, "Practices reproduced in homes, offices and cities condition each other in different ways and with varied consequences. Some interactions result in mutual adaptation, others in destruction, synergy or radical transformation" (2012: 86). Sustaining (and creating a boundary around) moral economies of a household is a lot about power, struggles and the ability to inhibit others from being or becoming carriers of certain practices or about enforcement of commitment to other practices. It is about negotiations and compromises about what practices should be performed in the home and thus constitute the moral economy.

Sometimes new technologies enter this battlefield and have to find their way into the space of the home. Perhaps they get recruited to different practices, which are fighting for time and space in the daily life of the household, and they may be involved in the establishment of new compromises, become allies for some practices or projects – for instance a parenting project or a husband's 'avoiding standby-consumption' project – or become the source of conflicts over which practices they 'belong to'. Moreover, it could perhaps also be argued that the negotiations between two committed carriers, for instance between a daughter and a father concerning the temperature in the house, may be seen as competition and eventually compromise between a dressing practice and a comfort management practice. This compromise may possibly result in new 'innovative' heating and/or dressing practices that are somewhat the result of a 'cross-fertilization' between the two practices. Equally, competition between co-located TV-watching practices and parenting/bed time practices may result in the development of new innovative practices – which may include the eFlex equipment as a new element to perform this new practice that re-establishes 'order' in the moral economy of the household.

Thus, focusing on 'moral economies' and the power struggles involved in maintaining this 'moral, temporal and spatial order' through the coordinated performance of certain practices and the meanings they carry says something about the multitude of ways technologies can be given life and meaning as a result of these social interactions. This perspective is also sensitive to how these social arrangements – which do not consist of 'communities of practice' but often of 'competing practitioners' who are *co-located* in the space of the home – are responsible for innovations in practice. Changed performances and experimenting with variants of practices can thus be the result of social interactions in the home and the introduction of new 'material elements' that disturb this order.

However, I should also remember to point out that although the specific performance of practices and integration of elements may be particular to different specific 'moral economies', of course all carriers draw on socially shared elements and practices for which the 'boundary of the home' makes no sense. In other words, dominant or institutionalised social practices also set the frame around which elements circulate and which practices 'meet' at all in the home. It is safe to say that it is not just in one particular family that 'doing the laundry', 'watching TV' or 'eating a family dinner' makes sense – they are *social* practices. Thus the specific, unique performance of a practice in each family, and the particular configuration of patterns and rhythms of practices that constitute 'family life', should still be seen as somewhat conditioned by these overall institutions and structures – which the continuous performance of practices on the other hand takes part in slowly developing as well.

Long-term co-development between practices and systems

In continuation of the above discussion, I would also like to reflect a bit on the long-term co-development between practices and systems and the implications for product development. In a domestication theory perspective, the conversion phase signifies how a household's specific appropriation and understanding of an artefact is signified to the outside world (Aune, 1996) – conversion implies how we 'talk about' and 'show off' technologies we have appropriated. As I wrote in the theoretical section on practice theory, referring to Gram Hanssen (2011), thinking about this in terms of practice theory means that conversion entails a 'showcasing' of the practices the technology has become part of to potential carriers outside the household. Such practices could for instance be the practice of surveying or 'managing' your children's TV watching or whereabouts through smart home energy management technologies. If this new practice manages to attract a cohort of faithful practitioners and spread, then product developers may seek to develop products and systems that play up against and build on this new practice – it creates the conditions for further redesigns of the material element needed to perform the 'new' practice. The household as a space where practices meet and compete or collaborate are thus important 'sources of innovation' of new provisional practices, which may recruit more practitioners.

The point about how producers may be developing products for new practices – and these new products may in turn take part in developing other entirely new practices – represents a good opportunity to move from a short-term perspective on the situated trialling, interaction and compromising, through which domestic practices may change and spread, towards a long-term perspective about the co-development between systems and practices. Doing this, I am returning to some of the discussions in the 'transition pathways and dead ends' section. What I want to point out is that it matters how the 'smart home' vision more specifically is designed – what technologies, market models, rules and regulations are developed – for what practices are developing and vice versa. If the smart home vision comes to build on an idea of householders as comfort-seeking consumers that aim to delegate control to technology, then technologies and regulations etc. that 'fit' this idea are sought to be developed.

Of course these designs and scripts may be utterly overthrown when they are 'absorbed into everyday ways of living', but the point is that a 'hedonistic comfort and convenience-seeking consumer' role may likely entail the development of certain practices over others, which may lead to the path development of a certain system or regime. As my eFlex interviews showed, the eFlex equipment, such as the IPod Touch, was used occasionally in relation to leisure practices of playing games or surfing the internet and introduced new ways and places of doing this – for example for Martin's wife, who had started doing these things while 'on the move', i.e. on the train ride to work. Whereas these practices are fairly dominant and well established already – and possibly would have 'captured' these eFlex householders sooner or later – and while these 'entertainment features' were not a big part of specifically the eFlex project, such tendencies are dominant in the field in general, as we discuss in paper 1.

Arguably, system designers that cultivate the 'funwashing' idea described earlier could promote energy systems that co-develop with certain practices, which lead to a transition pathway that may indeed not entail a 'sustainable regime'. Continuing this argument to other parts of the smart grid system, such as electric cars, as we write in paper 2, in one of the families I interviewed, the introduction of an electric car in the family meant that bicycle rides were now exchanged for electric car rides. Eventually, perhaps, the domestication of the electric car means that these new electricity-consuming practices become 'black-boxed' and unquestioned and 'normal'. The development of such new patterns of normal mobility practices is "made possible by the circulation of new and different materials, meanings and forms of competence" (Shove et al., 2012: 73) and creates a new backdrop or context for which systems are designed that may further continue this development. An obvious example of how the system *makes* demand is how the electricity system actors at the beginning of the 1900s actively promoted new ways that households for instance could use electricity beyond merely for lighting in order to level out peak loads. This created a number of practices that would depend on electricity and on the further development of such a system (Shove, 2012).

Skills, embodiment, practice biographies and projects

Up until now, I have discussed the importance of technologies and meanings for the development of practices, and I have discussed how practices are connected and interact in a domestic setting. However, the importance of skills, competences and know-how for the performance and development of practices certainly also deserves a final word in the context of the smart grid. It was very apparent in the eFlex project that managing and interpreting the portal, for instance, required some skills that many of the participants did not have. Although some of the most 'technical' of the participants could 'transfer' some of the skills they had previously picked up through their work as IT consultants or engineers, for instance, to perform the new practices related to the 'flexibility project', many participants simply did not have the skills to start engaging in the project. For many of the wives of enthusiastic participants, for instance for Benny's wife Marie, the equipment represented something very strange and unfamiliar, and something that they could not master. Accordingly, it also seemed rather meaningless to them – or more precisely, because they could not use it, it couldn't become part of a meaningful practice to them.

In this sense, of course, skills and meaning go together, just like some of the tools integrated into past and almost extinct practices seem absolutely odd and meaningless to us today, such as a 'larding pin' used for preparing meat[v]. If such a device was introduced to me, surely I would be quite bewildered about how to use it. Likewise, solar panels seem like a less obvious choice to invest in, perhaps because they are not yet part of many meaningful practices such as a new kitchen or a new car is, and because most of us likely don't have the skills to make the panels work or useful 'ready at hand from other practices'.

However, as Strengers (2013) writes, such devices can become part of new energy producing practices, for example, through which skills and meanings co-develop and spread. Importantly, thus, it is not just practices that change as they are taken up and reproduced, but also the 'carriers' that change as a result of this interaction (Shove et al., 2012: 69), and "new levels of practice comes within reach as competence develops" (Shove et al., 2012: 71, see also Juntunen, 2014). That practitioners pick up skills, as they become involved in different practices, may seem self-evident, but nonetheless I would argue it has an

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[v] The example of the larding pin is from the film of the 'Extraordinary Lecture' "How social science can help climate change policy" held at the British Library 17th January 2011. See more amusing examples of old kitchen tools as well as an excellent introduction to practice theory in the film of the lecture, which is available at: http://www.lancaster.ac.uk/staff/shove/lecture/filmedlecture.htm

importance for how we approach the idea of investing in a heat pump, for instance. In Wallenborn & Wilhite's words, "bodies are repositories of a unique and explicit form of knowledge about the world" (2014: 56) and "learning, sharing and carrying are typically and perhaps unavoidably transformative, both of the practitioners involved and of the practices they reproduce" (Shove et al., 2012: 73). The point is that if we have acquired skills (and meanings for that matter) required to operate such a device previously through our professional life (e.g. working as an engineer or installer) or from having had an individual heating system previously (for instance an oil boiler as opposed to district heating), then we may be able to transfer these skills (and meanings) to the practices related to the operation of the heat pump and everyday comfort. In other words, the skills and "accumulation of expertise" (Shove et al., 2012: 73) acquired in a person's 'practice biography' has an importance for how new energy technologies are domesticated (see Juntunen, 2014) and for what practices they are prone to become carriers of. "Taking one path and not another configures opportunities for the future" (Shove et al., 2012: 78). In general, the commitment to certain 'roles' has an importance for the commitment to future practices – which underlines the argument above about the co-development between the consumer role, certain practices and the energy system.

If an individual has previously been engaged in projects such as renovating the house, setting up an IHC lighting system or have engaged with a new PV system on the roof, this person takes part in establishing an "organizing framework in which practices are integrated and in which new skills and possibilities emerge" (Watson & Shove 2008: 72). In terms of the opportunity to exploit already acquired skills and embodied knowledge from previous experiences in the development of new 'energy-producing practices' (Strengers, 2013) related to for instance micro-generation (e.g. PV and heat pumps), it is interesting to think about the ongoing 'de-skillness' in terms of 'craftsmanship' that is happening in Denmark, as more and more craftsmen are exchanged for people working in the 'knowledge sector'. Nevertheless, whether a household is prone to invest in a heat pump or being flexible with it is thus not just a question of whether they have the proper values and attitudes, whether they belong to the right 'segment', whether they have a house that is suitable to it or whether there are children and pets and plants or whatever that call for certain practices to be performed, which diminishes the 'flexibility potential' of the household, but it also has to do with the previous building up of forms of competence and skills in the household.

5.4 Discussion of research question 4

How do historical conditions and past and current controversies shape the present development and configuration of the smart grid? How can policies contribute to a sustainable configuration of the smart grid? (Papers 1 and 4)

In this last part of the discussion, I want to direct more explicit attention to some of the issues I have touched upon previously, concerning how the present smart grid development should be seen as an emergent outcome of historical developments in the ICT and energy sector. Moreover, I want to emphasise how the 'future path' of the energy system is (still) an open and contested issue – and that 'things may not go according to plan'. This opens up for recognising the many paths that the energy system transition can take and the wide variety of ways that households can have a role in the energy system transition. Finally, I want to discuss some of the dynamics that policy makers should be attentive to in relation to the current energy system transition.

As I write at the beginning of the discussion, in paper 1 we argue that the current vision of the smart-home-in-the-smart-grid should be seen in the light of the historical development of ideas relating to the use of ICT in the home. Thus, gaining an understanding of the complex history this vision of the smart home is born from may tell us something about the politics and interests this vision entails, and what dynamics it is going to further co-develop with.

Our analysis has shown that the smart home development may indeed not be the 'sustainable track' that it claims – or hopes – to be. Although our account of the smart home in a historical perspective could have been much further elaborated in paper 1, we illustrate how present ideas and developments of the energy system and the smart home are contingent on history. On a very foundational level, the development of micro-electronics has had an important part to play for the current smart home imaginaries, but so have arguably circulating ideas about comfort and convenience, structural re-arrangements in the labour market and systems of provision, as well as "the strong forces behind the development of the intelligent welfare home" (Nyborg & Røpke 2011: 1856). We do not enter into such a discussion in paper 1, but focus on a narrower conceptualisation of co-development, a deeper analysis that integrates such broader societal issues into a historical perspective could have been interesting to unfold further.

Moreover, we sketch out quite briefly some of the current issues and controversies relating to the smart grid, which may 'expand the frame on technology' (Marres, 2012). As we write, several issues have emerged such as householders' (and those who speak for them's) concern for their security and privacy. Several reports have been written that warn about the risk of hacking and vulnerability to acts of terror that arise from the 'digitalisation of the energy system'. Other concerns relate to "the vast amount of person-sensitive digital data that a smart grid system produces" and "the fact that explicit data about electricity consumption and the knowledge they reveal about everyday habits can be misused by criminals or insurance companies" (Nyborg & Røpke 2011: 1856). If such actors got hold of detailed data about electricity consumption in a specific household, they would for instance be able to identify patterns when no one is home during the day, or they could detect if new energy-consuming (and valuable) devices have been bought for the home.

Issues of 'who is in control' – also beyond the conflicts over 'control', which new energy technologies can spur in families, as I write in paper 3 – for instance in terms of ownership of data or external control of electricity consumption are also flagged. Although many heat pump owners are happy to have their heat pump monitored and 'optimised' by an external actor, so they are certain it runs optimally, several householders express concern that they don't quite know how to operate it and that it will 'run wild' in terms of electricity consumption. Others express a feeling of eeriness that someone from outside is surveying and turning their heat pump on and off, and they feel 'out of control'. Others are actively 'taking control back', as in the case of the innovative user Eddie, who proudly proclaimed that although DONG Energy controlled his heat pump, he 'overruled' their control of the heat pump. All in all, such controversies underline how many householders insist on being in control and taking part in the development, and that the smart grid is not (and should not be) "too complex for the public" (Schick & Winthereik, 2013).

In paper 4 we also put emphasis on how the current socio-technical diagram (Akrich et al., 2002) of heat pumps has come to be as it is through a historical account of the events and struggles that have shaped this technology's development – and which explains its relatively modest position today. What I would have liked to do was to explore more thoroughly the socio-technical diagram from the perspective of households. However, gathering empirical insights into the historical development of practices related to heating comfort in Denmark and the 'system' around such a heat pump in a household would require an extensive research journey I have not had the time to embark on in this project. Nonetheless, it is clear that controversies and actors' interests will shape a smart grid rollout, and so will the emerging social practices the smart grid forms and is formed by.

Clearly, there are energy system actors who have competing action programmes to the one that is carried by the electricity sector – a sector that has otherwise worked very hard to construct and disseminate interessement devices such as the eFlex user study, as we argue in paper 2. As I discuss in the beginning of this thesis and in my papers, notably in paper 4, the electrified smart grid pathway is under attack by other understandings of what direction the future energy system should take. These are not just the differing understandings of energy system actors, but also of the households, who have agency in relation to a transition of the energy system – and in a practice theory perspective these are important 'performers' in the system.

Policies and pitfalls

Smart grid technologies are only monstrous if they are 'allowed' to be so. Being attentive to dynamics such as those described in the present thesis may provide some clues as to how we can support a 'good science' (Latour, 1997) and technologies that stand a fair chance of being part of a more 'sustainable configuration'.

From the viewpoint of the Danish net companies (i.e. electricity distribution), the smart grid vision is a sustainable solution to a common challenge, where there are 'no losers'. Undeniably, the integration of more wind energy into the system is a good place to start for a sustainable transition of our energy system, and certainly, from a socio-economic perspective, the use of this wind power within the Danish borders seems like a sensible suggestion. However, does this mean there are no other 'right' ways to go about a transition than the 'top-down' smart grid path I have described in this thesis? And what should policy makers be attentive to in terms of supporting a sustainable development path?

To start with the first question: for sure, a sustainable transition can take many development paths, also other paths than the electrified, 'technologically mediated' and economically rationalised smart grid path. Although wind energy is a dominant actor today, we cannot be sure that the erection of wind turbines will proceed as politically desired. Already today, energy companies are experiencing big problems in finding land areas where they can set up wind turbines, as many citizens are resisting this (see e.g. Bergek, 2010). This does not mean, however, that wind energy cannot become the main energy form in the future – it may just not be in the institutional set-up such as the one we see today. Instead a wider variety of ownership structures may need to be developed, which support a wind energy transition (Wolsink, 2012).

Besides the development of decentralised technologies or micro-grid systems, which is happening several places in the world, perhaps there should also be a focus on developing more decentralised *ownership structures*. However, it is also still possible to imagine a smart grid transition that has many of the elements and the institutional set-up I have discussed in this thesis, for example, centralised wind power implementation, electrification of transport and heating etc., which points in a sustainable direction. In this context it is important that emphasis is put on the features in this vision that generally support energy savings and not just energy 'flexibility' – that more attention is given to features that position energy as a valuable and at times scarce resource, and not as something intangible that automatically flows out the socket whenever you want it. We should probably be cautious about developing smart home energy management technologies that do a good job providing 'flexible consumption *for* you' and succeed in hiding energy's role in and for everyday practices. This also entails a policy focus on smart grids that are not intimately related to the idea of 'funwashing' and of 'unprecedented luxury'.

Policy makers should on the other hand put more resources into exploring the 'socio' in socio-technical transitions. That is, they should not just explore how technological systems co-develop with social practices, which may have negative energy impacts, but also remember to develop ideas and research into how *institutions* and *systems of provision* could be re-configured and how this relates to technologies, social practices and patterns of energy consumption. Being attentive to dynamics such as the ones Strengers (2013) and I have explored in this thesis – and several others have begun, as I mentioned in the introduction – enables a more 'open' or 'informed' policy-making process, I would argue. By this I am not saying that I am contributing a certain 'truth' that can inform the 'right decisions'. Of course, politics, interests and power struggles will not be taken out of the smart grid, because we know more about these dynamics, but putting them out in the open lays the foundation for a more inclusive process where interests and power relations are visible and can become matters of concern, also for the public.

Moreover, policy makers should also recognise and support 'creativity on the fringes', and I also call for more research into *why* and *how* we involve 'citizens', 'consumers' or 'users' in planning and innovation processes. 'Citizen participation' is a well-established research area that presents many arguments for why publics should be engaged in the development of cities or infrastructures. It is for instance argued that it is a democratic right 'to be heard'; that citizens have very situated and contextual knowledge, which the planners or systems designers do not have access to; it strengthens citizens' sense of ownership to the projects; it supports 'empowerment'; it mobilises 'voluntary resources', and improves democracy and so on (Agger & Hoffmann, 2008: 12). This literary tradition share ideas with work on 'user-oriented innovation', i.e. that users are valuable resources that should be included in the design of new products. From the strategic perspective of manufacturers – or for instance the Danish government, as I argued earlier – these users can beneficially be included in various ways and for various reasons. The argument is that by gaining in-depth knowledge on users' 'unacknowledged needs and preferences', we can design products that better 'fit to them', or we can use them as co-creators, which also results in more 'innovative' products. Finally, it is also argued that we should recognise users' capabilities as full throttle innovators and device methods to be able to tap into their creativity.

Citizen participation and user-oriented innovation literatures are different in the sense that whereas 'citizen participation' seems to be based more on a democratic ideal and focuses on involving the public in 'common good matters' such as planning a city area or infrastructures, user-oriented innovation has a more 'commercial' backdrop: here publics are mostly invited in order to improve the competitiveness of a product. Moreover, these literatures are somewhat divided by having different traditions and methods of engaging people. However, as the eFlex and DREAM projects have shown, these 'divisions' are probably increasingly dissolving, and both fields are drawing on a multitude of logics, disciplines and methods, such as anthropology, STS, design thinking and co-creation methods.

I think, however, it would be beneficial to put even more work into *designing* such 'user-involvement' processes and in general to give more attention to designing stakeholder processes that 'work better', in the sense that they end up in a process where the inputs from the users or other stakeholders to a higher degree become part of solutions. Moreover, I would argue we need more research that also critically explores and discusses the ways user-citizen-consumer involvement is being done today *and for what reason or purpose*. It is my impression from the field and from talking with my research colleagues working with planning and citizen involvement that too often these user involvement processes are not very fruitful, and there seems to be a lack of interest in actually using inputs from the users or knowledge about the dynamics of everyday life. Thus, in these cases user involvement projects do not appear to be part of a development process to actually 'support democracy', but rather so that system designers can strategically say that they actually 'did ask the users' or that 'we did hold a citizens meeting in the town hall'. In other cases such 'user involvement projects' seem to be born out of an interest in 'selling' a certain vision or product to the users or citizens, and this vision will not fundamentally change as a result of the interaction with the users.

Lastly, I will put some final perspectives on my discussion of the issues that relate to the perpetual mainstream appreciation of theories about individuals' attitude, behaviour and choice (Shove, 2010), which I have pointed out throughout this thesis. The available theories in the social sciences that could extend our insights about dynamics of consumption and sustainable socio-technical transitions are vast – some of the most important ones are part of this PhD thesis, I would argue – but it is only a fragment that continues to be the basis for policy-making (Shove, 2010). Drawing solely on only theories that focus on individuals' attitudes, choice and behaviour first of all produces limited knowledge about what is actually 'going on' in everyday life, and why patterns of consumption evolve as they do – and it is difficult to address a problem if we are basically ignorant to what actually constitutes the problem. Secondly, these approaches only have a very little chance of making the radical changes in society *in the scale that is needed*, as these theories merely reproduce the existing norms, systems and structures that are at the root of sustainability problems – they do not question them, and they provide no hints as to how to change them.

These approaches may be popular among policy-makers because they simplify the problem as one of persuading individuals to take responsibility and change attitudes, as I wrote in the introduction. However, as I have discussed in this thesis, a lot of consumption is the result of the performance of 'normal' (mentally and bodily) routinized social practices that are not in focus in energy-saving measures, and which we do not fundamentally question in everyday life. Focusing on the societal configuration of practices and how they develop would probably provide some more hints as to how policy-makers could change patterns of consumption.

Thus, although smart energy technologies may to some extent help people reflect on their energy consumption (at least for a while), the point is probably also more that the gains from such initiatives that are focusing on individuals are relatively small compared to the major system challenges we are faced with. These challenges relate to, for instance, how the functioning of our social and economic systems and the achievement of societal objectives such as employment and welfare etc. are dependent on continued economic growth. This growth is mainly driven by increasing consumption, which is institutionalised and required of us if we want to take part in a 'normal life' and in 'normal' (and in a sense black-boxed) social practices related to housing, leisure, parenting, employment, etc. Such dynamics are evidently highly unsustainable and difficult, if not impossible, to change if we put all our energy into targeting individuals' attitudes and completely ignore 'the bigger picture'. It would somewhat correspond to having a bull in a china shop, but focus on trying to catch the mouse in the corner. We would probably avoid some damage if we catch the mouse, but I would argue for giving the bull a little more attention – although it may be a scarier and more difficult encounter.

Economic models, with their implicit and unquestioned assumptions about rising demands in the future, are especially powerful in my opinion. An article in the newspaper Politiken from 10 October 2014 provides an example. The front-page article, "UN Panel [i.e. IPCC]: Nuclear power and shale gas will help us save the climate" (Færgeman & Saietz, 2014), was written in relation to the upcoming release of IPCC's Fifth assessment report. The main message in the article was that, according to IPCC, there is no way we can avoid using energy forms such as nuclear power and shale gas as well as CCS if we are to "avert a climate catastrophe". The reason for this is, according to IPCC, the dramatic rise in consumption, which will force us to use other sources that are not renewable. "Even in the most optimistic scenario, we will still see a doubling in energy consumption" in 2050, as Torben Chrintz, the president of Concito, the green think tank, expresses it.

What I want to discuss is not so much whether nuclear power, CCS or shale gas are a good idea, but, rather, I want to discuss the assumptions about demand that are constantly perpetrated and 'naturalised' as something that will unavoidably happen. If we continue the same course as we are on now – i.e. if we do not question our systems and practices as discussed above – and only 'tinker' with making technologies more efficient or try to make consumers make green choices in relation to a fraction of the practices performed in everyday life – then there is absolutely no doubt that demand will rise, especially as the third world is increasingly becoming wealthier. However, I think it would be beneficial if the assumptions behind this increase in demand were put more out in the open and questioned. IPCC's report and conclusions are subject to some controversy and are being critiqued by green organisations that apparently do find it possible to have a future where even less energy is used than in the 'hyper-optimistic' scenario of IPCC. In the green organisations' calculations we can accordingly make do with purely renewable sources. However, still, the premise of an increasing demand is very sparsely discussed in the public. Certainly, some developing countries will need continuous growth in many years to come, but other countries will certainly not need this. It is often stated 'as a matter of fact' that 'demand will rise' and then we discuss other things such as how to meet this increasing demand, but what lies behind these assumptions about an increase in demand? What assumption do the mainstream economic models integrate? Should we question their in-built 'needs' and continuous growth, which naturalise a development where the Western world continues to have even more space to live in per household and even more cars to drive in 50 years? The problem with growth is also that, historically, it has always been material things we have wanted more of. A macro-actor succeeds in keeping black-boxes closed and the network-building and activities unquestioned, and in this sense the mainstream economic models are very powerful and extremely un-democratic – or even 'tyrannical'. Knowledge is power, and if these questions are not brought out into the open, then a sustainable transition of society at large is will be challenged.

This leads me to my last point, which is that controversies and disagreements can indeed be fruitful and productive, as I started arguing above. Even though controversies may arise in relation to (global) political commitments to 'turn things around' and move in a more 'sustainable' direction – which is also a contested notion in terms of what this means and entails – this doesn't mean that we should seek to 'hide' or remove disagreements. We get smart from engaging in disputes, and our practices may change as a result of it. Therefore, trying to navigate and move towards a sustainable future means learning from householders and recognising them as skilful practitioners. It means inviting householders into the engine room to take part in finding the path towards the goal of a more sustainable energy system and a more sustainable way of living, and to take part in discussing fundamental questions about the way our society is configured. What are the interests behind visions of the smart grid? Are there other interests than a green transition at play, such as justifying a liberalisation of the energy sector or the possibility of creating a new innovation platform for providing new services and products to customers and securing economic growth? If we set out to change someone's 'behaviour', but forget to tell them that what they change behaviour "towards" could in fact be different, then we are aiming to keep black boxes closed and certain actors in power – and these sealed black boxes and powerful actors may well play an important role in the current unsustainable configuration of society.

6 Conclusions

In this PhD project, I have explored the role of households in the development of smart grids in Denmark. Through the research process, I have investigated what the smart grid vision entails, what roles households are imagined to have in it, what constitutes this role and how system builders strategically construct this role. I have also set out to investigate if householders have other roles than the ones that are 'designed' for them – among other things through a thorough investigation of how families domesticate smart home energy technologies and what practices are at play in relation to this appropriation. Finally, I have been concerned with examining how the current development of the smart grid should be seen in relation to historical conditions and controversies, where householders have played an active part, and I have argued that contemporary discussions and controversies are also going to form the future development of the energy system.

My research has shown that the vision of the smart grid in Denmark is dominated by economic and technological rationales. Households are in this vision mainly articulated as consumers, who have an individual responsibility for the functioning of this future system through their consumption choices. They are expected to invest in heat pumps and electric cars and to use electricity flexibly – either by leaving control of consumption to technologies or to energy companies, or by actively making choices themselves. Parts of these findings are based on participant observation in the eFlex project, which was a user-oriented innovation project that DONG Energy had hired a consultancy firm to conduct. By using the case of the 'eFlex project', I argue that energy companies may seek to actively construct a role for households that fit with their interests and action programme by conducting user studies, through which householders can visibly become 'allies'. In relation to this analysis we introduced the concept of the 'aligned user' to the field of user-oriented innovation to supplement notions of, for example, the represented user, the projected user and the real user (Schot & de la Bruheze, 2003).

However, an analysis of fieldwork among participating households in the eFlex project illustrates how households often take other roles in the system such as innovators and developers of the system. Other studies in relation to another smart grid project support this finding by emphasising householders' capacity as 'self-builders' and underline how householders also value their role as 'community citizens' and orient themselves towards social norms.

The households that participated in the eFlex project were among other things expected to 'test' new smart grid energy management technologies. Interviews and observations in the households revealed how the new technologies interact with a wide range of domestic practices – they are both absorbed or domesticated into existing practices, but they also take part in changing them and in creating new practices in the household. Such energy management technologies are moreover prone to creating conflicts in families, as they are absorbed into everyday ways of living, mainly for two reasons. Firstly, because they have direct consequences for electricity consumption and heating (when the heat pump is controlled), which is an element in a wide range of domestic practices that are performed by all members of the household. Secondly, they disturb domestic order because the demands for flexibility have implications for the coordination and rhythm of individual paths and collective practices and projects that constitute the moral economy of the household.

By drawing on both practice theory and domestication theory, I am also discussing how practices are connected in the setting of the household. In this conceptualisation, which needs further elaboration, the space of the home is seen as an 'innovation junction', where practices are co-located and can 'cross-fertilize', and where the constant work to uphold a moral economy of the household creates tensions and conflicts between carriers of practices over getting to perform individual practices. Negotiations and compromise may lead to innovations in practices. New technologies such as smart home technologies enter this scene and may become part of these conflicts, as well as negotiation processes. It is also argued that the domestication of new 'smart technologies' is also contingent on the 'practice biography' of the users and their accumulation of skills and competences – for instance from engaging with other practices that require the same skills. The development of new practices, which the technologies have become part of – such as using energy management equipment to survey and control spouses and/or children – may succeed in attracting more carriers and in defining new social meanings and norms. These new practices may then be the backdrop on which new technologies and systems are developed and thus the smart home co-develops with domestic practices.

In relation to the specific vision of the smart home as it is articulated in Denmark and other countries, we argue that the smart-home-in-the-smart grid may co-develop with more energy-consuming practices and expectations of comfort and convenience. In this context we argue that the smart home may in fact be characterised as a Trojan Horse, which despite the opposite intentions may introduce and create new technologies and practices in everyday life that overall may have a negative energy impact.

This conclusion is derived from an analysis of the old concept of 'the smart home' and how it has developed historically. The present conceptualisation of the smart-home-in-the-smart-grid can be seen as the latest addition to a family of ideas that have developed over time, which relate to using ICT in the home to 'augment them' and make them smarter, more convenient, safer and more entertaining. Thus, we conceptualise the smart home as a 'melting pot' containing these different trends. The current understanding and envisioning of the smart home has co-developed with these established ideas about what a smart home is. We argue that one dynamic that can explain this co-development may be related to strategies of 'funwashing'. This is a concept we introduce to account for the way actors in the electricity sector may put an emphasis on bundling their smart home energy management technologies with entertainment, comfort and convenience features to make them more attractive to buy for their customers – and this dynamic may have negative energy impacts, as mentioned above.

A historical exploration of the development of heat pumps in Denmark also shows how the current configuration of the energy system is not the result of some sort of technological supremacy or the logic of market forces. Rather, the development of such technologies and systems involves conflict and controversy, which implicates a wide range of actors, including householders with 'zest and pioneer spirit' – and the current position of heat pumps in the energy system could indeed have looked different if other actors had 'won the battle'.

Finally, I argue that the energy system transition in the future will also be shaped by controversies and co-develop with social practices, and I make a few remarks in relation to policy-making in this connection. I firstly urge policy makers to be attentive to how 'funwashing' elements in the smart grid vision may have negative energy impacts. I accordingly suggest that policy-making should instead promote a technology configuration that supports the elements in the smart grid vision that seem to support energy savings and more sustainable practices, and meanings related to the 'scarcity' and specific rhythms of renewable energy sources. Secondly, I call for more attention to the involvement of the public in relation to the 'design of the future energy system'. Hence, I suggest more resources are invested in designing processes that can fruitfully engage multiple stakeholders, including households, in the development and discussion of the coming energy system. I also call for more resources into critically exploring the current ways citizens-users-consumers are involved in the development of projects of public interest.

Moreover, in terms of policy measures aimed at supporting a sustainable development, I suggest abolishing the current dominant, narrow focus on changing individuals' attitudes and choices. This should be substituted with a perspective that recognises the major system challenges we are faced with, such as, for instance, problems related to how our pension systems are dependent on continuous economic growth and how many social practices – related to things such as being a caring parent, socialising or having fun – are bound up with and dependent on material things. These are some of the strong dynamics that are driving increasing energy consumption and an unsustainable development at large. Thus, the systemic challenge that a sustainable transition poses requires that current institutions, systems and social practices are interrogated. Similarly, current assumptions and black boxes relating to the economic system and to expectations of demand need to be questioned, so that households can play an active role in the development of a future, more democratic and more sustainable, energy system.

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8 Appendix

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8.1 Households in the smart grid: On the co-evolution between domestic practices and the energy system

Sophie Nyborg & Inge Røpke

In the coming years the energy system is bound for a low-carbon transition due to concerns about e.g. climate change and insecurity of supply. In Denmark, as in many parts of the world, policy makers and the energy industry present the vision of the 'smart grid' as one of the most promising solutions to the upcoming challenges.

This digital modernisation of the electricity grid is thought to enable better integration of fluctuating renewable energy sources and handle an expected increase in electricity demand. However, many actors are still negotiating the specific pathway the transition should take.

This 'transition-in-the-making' has already been investigated in the field of socio-technical transition studies, which have elaborated on e.g. different future transition pathways of the electricity system. However, an underexposed aspect of these studies is the agency the domestic sphere has in socio-technical transitions. As some scholars argue, nonetheless, systems of provision, infrastructures and domestic practices co-evolve. Hence, we argue that the specific role households have in the energy system – and the domestic practices these entail and are configured by – will be very important for the type of transition pathway to develop and e.g. whether the transition will be sustainable.

The aim of this paper is to explore the kind of roles for households that are being constructed in the smart grid development and discuss which practices are central to them and how they can be co-developing with emerging technologies and systems of provisions. The theoretical contribution of the paper is a discussion of how a practice theory and a transition theory perspective can be brought together to refine the dynamics of transitions. The paper draws on desk studies of reports on the smart grid vision, participation in smart grid events and field work among system designers and households in a large smart grid demonstration project.

9 Paper I

9.1 Energy impacts of the smart home – conflicting visions

Energy impacts of the smart home – conflicting visions

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alternative energy systems (AES), savings potential, homes, consumers, energy consumption, smart metering, everyday life, practices, sustainable development, energy saving technologies, advanced metering, information and communication technologies (ICT)

Abstract

To support the transition towards an energy system that is based 100 percent on renewable energy sources, the smart grid is presently undergoing rapid development in Denmark – a hype that can also be seen in the rest of the world. Many actors are playing in the field, and the present situation is characterized by great uncertainty as to the direction of the development. The paper focuses on the role of households in the smart grid visions proposed by a broad range of stakeholders. It has two aims: first, to sort out the threads of the discussion; what visions are formulated regarding the role of households in the smart grid? What visions are articulated for the functionalities of the smart home? Secondly, we critically investigate these visions to explore if they support the development of sustainable energy consumption.

We claim that the smart home in the smart grid is the latest addition to a family of ideas emerging in relation to the application of information and communication technologies (ICT) in the home. The smart home is thus a melting pot of such different trends as automation of household chores, entertainment and energy management. These different ingredients of the melting pot co-evolve, we argue, and we suggest that the co-evolution may well have negative consequences for the overall energy impact of the transition. The smart grid could become a dynamic that constructs and normalizes new energy-demanding practices and facilitates escalating expectations to comfort. This paper only begins the exploration of the reported discussions; much more research in this area needs to be done.

Introduction

Interest in smart grids and smart homes has risen dramatically in the last few years. The hype surrounding this prospective revolution in energy systems is seen worldwide, for instance in the 3.4 billion dollars that the Obama administration in USA recently set aside for smart grid R&D, or in Europe's dedication to smart grid research in the Seventh Framework Programme. Also China has jumped on the bandwagon and announced in May 2009 an aggressive framework for smart grid deployment.

For the IT sector, the smart grid is being highlighted as one of the big opportunities for using information and communication technologies (ICT) in addressing climate change and subverting IT's hitherto dominantly negative impacts on energy consumption in e.g. households (The Climate Group 2008).

Modernizing the electrical grid with digital technologies also holds promises for other stakeholders worldwide, such as the energy sector. In the USA, the smart grid discussion is mainly concerned with avoiding brownouts and blackouts in an electricity grid that is strained in periods of peak-demand, whereas the theft of electricity and ICT surveillance of the grid is a concern in e.g. Malta and India (Tornbjerg 2010). In most parts of the world, however, the smart grid is under all circumstances considered an important part of a sustainable transition of the energy system.

In this paper, we are concerned with the Danish discussion, which mainly focuses on the growing integration of wind energy. For the Danish system, the socio-economic benefits of integrating more fluctuating renewables depend on a better utilization of wind power by Danish consumers, through intelligent management of their increased electricity consumption. Recently, the Danish Minister for Climate and Energy mobilized a 'smart grid network' to work on recommendations for how Denmark should future-proof the electrical grid to handle up to 50 percent renewable energy, mainly wind, by 2020.

The present situation is characterized by great uncertainty regarding the future direction of the development. Many stakeholders are showing marked interest in this field and the last few years have featured countless conferences, seminars, meetings, reports and white papers concerning the future of the smart grid in Denmark. The discussion is becoming even muddier, since the field is a meeting place for such diverse sectors as the electricity sector, the transport sector, the IT sector, the housing sector and the district heating and heat pump sector, which are all pulling in different directions and trying to negotiate the character of the transition.

Households are often conceptualized as smart homes in the smart grid, and different visions about the future role of households in the smart grid are part of the discussion.

The purpose of this paper is first of all to sort out the main threads of the discussion: What visions are formulated regarding the role of households and the functionality of the smart home? Secondly, we critically investigate these visions: Will the visions actually support the dynamic that is necessary for a transition towards more sustainable energy consumption? Will the development of the smart home potentially contribute to enhanced energy consumption?

The paper is based on reports and other publications on the smart grid and the smart home, as well as participation in meetings, seminars and conferences. Also, semi-structured, unstructured and informal interviews have been conducted with relevant actors in the energy, IT and housing sectors as well as in public sector organizations.

The research object for this paper – the smart home in the smart grid – is only the latest contribution to a long history of different understandings of what the smart home is. To contextualise the present discussion, the paper starts with a brief presentation of the history of the smart home. The visions of the smart grid, as the framework for the smart home, are then discussed, followed by an overview of the role households and the smart home should play in the smart grid. In relation to this overview, we also present some of the discussions and disagreements relating to the role that the visions ascribe to consumers. Finally, we argue that the smart home is a melting pot of different trends and that the smart-home-in-the-smart-grid co-evolves with these other trends. This co-evolution can potentially have negative consequences for energy consumption.

The smart home in a historical perspective

The smart home in the smart grid can be seen as the latest addition to a family of ideas emerging in relation to the application of ICT in the home. The concept of the smart home is thus just one among many belonging to a large group of concepts such as the smart house, the electronic cottage, home automation, the networked home, the intelligent home, and the digital home (Miles 1991, Berg 1991).

The introduction of microelectronics offers inexpensive and powerful information processing that can be used to monitor, manage and manipulate in a multitude of consumer products – to interconnect various items of domestic equipment within the home, and to manage systems in the home from a distance. This technological potential opens business opportunities, and from the 1980s this potential was increasingly explored in various smart house projects, used as test beds for innovative ideas (e.g. in 1984, the US Smart House Project was launched by the National Association of Homebuilders, Miles 1991: 68). Over time, new ideas were developed, but some lines of exploration have been remarkably stable.

As illustrated in Figure 1, the smart home can be seen as a melting pot where different trends meet, influence each other, and sometimes merge

Most of the ingredients have quite a long history, and for each of them, new elements and trends have been added along the way. Just a few words on the main ingredients:

Automation of household chores (home automation): Mechanization of household chores was on the agenda long before the emergence of ICT, in relation to the introduction of the small electromotor. The motor could replace muscular strength and transmit energy for heating and cooling, and it was integrated in a wide range of domestic appliances – vacuum cleaner, refrigerator, washing machine, dishwasher, air conditioning etc. Microprocessors add a dimension by replacing or enhancing brain capacity – the ability to calculate, manage, communicate, and regulate – which can be used for increased automation of household chores and for managing them from a distance. Examples are the vacuum cleaner robot and automatic feeding systems for pets, but many more ideas belong to the future.

The safe and secure home: Combined with sensor technologies, ICTs make alarm and security functions possible – fire alarm (which can even unlock doors and call the fire brigade), burglar alarm, video door phone, monitoring water leakage alarm. Automatic management of lighting and television can make the house look inhabited when the residents are not at home.

Home systems management and energy savings: Energy systems in the home – heating, ventilation and air conditioning systems – can be managed automatically, for convenience and comfort. Increasingly, energy savings are emphasized as a central aim for energy systems management, for instance, by changing the temperature over the day according to needs. Also the lighting system can be managed for energy savings by the use of motion sensors to turn off the lights. The introduction of smart metering has added an extra dimension to energy savings in the smart home, since the provision of quick and visible feedback to consumers on their energy use is expected to encourage savings. Experiences with smart metering and feedback have already been the subject of much research (e.g. Darby 2008, Darby 2010, Hargreaves et al. 2010, Fischer 2008). The most successful examples seem to combine frequent information over a long time period with an appliance-specific breakdown, a clear and appealing presentation and the use of interactive tools (Fischer 2008).

Home entertainment: Individual entertainment devices – radio, television, music centre, video game console – have a long history, whereas networked entertainment systems are more recent additions that are advertised as a core element in the digital home. Devices are often connected through the home

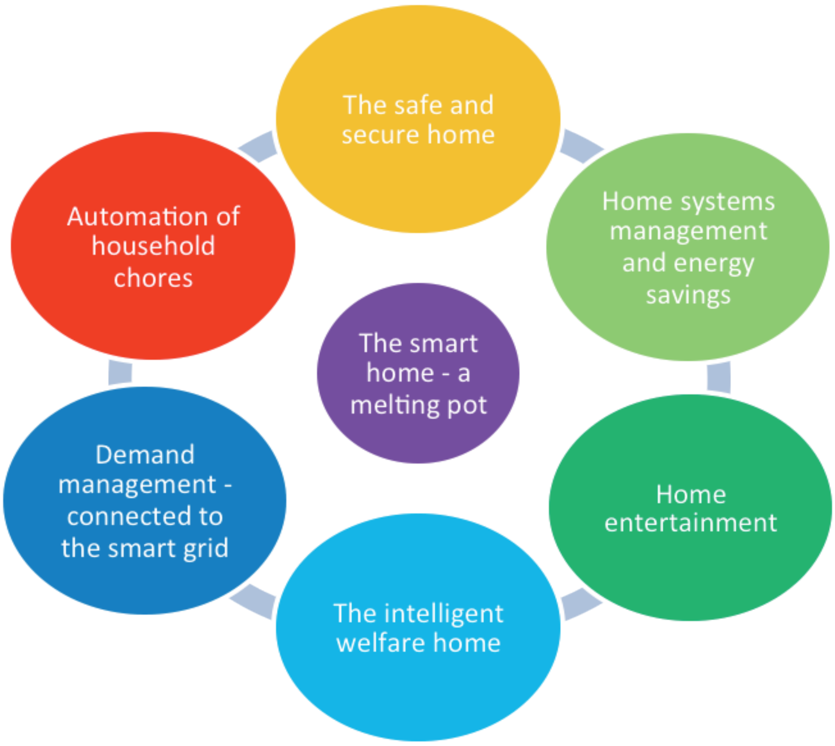

Figure 1. The melting pot of the smart home.

gateway, which also provides internet access to the home; and sometimes a server is used to organize the household's collection of films, music, games and photos, which can then be accessed from various rooms in the house.

The intelligent welfare home (health and care): ICTs are also applied in the development of equipment for physically disabled, and smart home installations form part of this trend. Examples of early smart home installations include remote controls (eventually voice-managed) for opening and closing windows and doors, drawing curtains, turning lights and music centers off and on, and lifting and lowering kitchen tables (Bendixen, Christiansen 1999). Internet connection opens new opportunities for taking care of people with ill health in their homes, for instance, by monitoring various health indicators such as blood sugar level at a distance, or giving advice on treatment of wounds on the basis of transmitted photos. Telemedicine and the intelligent welfare home will no doubt gain ground with the increasing financial pressure on the welfare state.

The smart home in the smart grid will add a new ingredient to this melting pot when demand management is enabled through household connection to the smart grid. When the possible outcomes of the transition processes related to the smart grid are considered, it is important to keep in mind that the various ingredients co-evolve and that this co-evolution influences the overall energy impacts of the transition.

Visions of a low carbon energy system and a smart grid

In 2050, the Danish energy system can be based 100 percent on renewables – mainly wind power, backed up by biomass – and electricity should be central to the energy system, covering up to 70 percent of total energy consumption as opposed to 20 percent today (Klimakommissionen 2010). This is the core vision recently published by the Climate Commission, which the Danish government appointed in 2008 to figure out how Denmark could become completely independent of fossil fuels in the future.

Wind is the most abundant renewable energy source in Denmark, and at present, wind power is also considered to be and become the cheapest renewable energy source (Klimakommissionen 2010: 36). Wind delivers its energy in the form of electricity, and the strong focus on exploiting wind energy implies that electricity will become the main energy form in the future energy system. Wind power can accordingly be used in the transport sector by electric vehicles (EVs), thus eliminating CO_2 emissions from gasoline. In heating of houses, electricity-driven heat pumps are to be used both in district heating systems and as replacement for oil burners in houses outside the district heating areas.

The commission report states, however, that a prerequisite for realising this vision is intelligent management of electricity consumption in households, institutions and companies – notably since electricity consumption is forecasted to be more than doubled by 2050.

Thus, some of the central challenges that a smart grid is to address are the following:

- Already today, Denmark has a relatively large share of wind energy in the system. Wind power cannot be stored effectively, so it has to be consumed when it is produced. The integration of fluctuating wind energy is facilitated by trading electricity with Germany and through the Nordic electricity market, Nord Pool. Here excess electricity can be sold when wind energy is abundant, and electricity from Norwegian and Swedish hydropower can be bought in calm periods.

Although this international trading is useful, it is not always beneficial in a socio-economic perspective, because electricity prices are sometimes very low when wind energy is plentiful. Recently, Nord Pool even introduced negative prices, which means that Danish electric companies have to pay to get rid of their excess energy. Therefore, increased integration of wind energy should be combined with increased use of the energy within the Danish borders, also in periods with heavy wind (Ea Energy Analyses, Risø DTU 2009). This forms the point of departure for the following issues.

- The increased national demand for wind-based electricity is expected to come particularly from transport and heating. The integration of electric vehicles and heat pumps, however, can enhance the classical problem with peak demand. Already today, peak demand resulting from two-three hours intense electricity use after working hours (e.g. from cooking dinner) means a very uneconomical energy production. This compels electric companies to have a lot of reserve power available, which means turning on entire power plants for a few hours high demand, and this is expensive.
- Furthermore, increased peak demand will cause a capacity problem in the distribution grid, because the cables are not rated for the much larger peaks anticipated as a result of the uptake of EVs and heat pumps. This means that the electricity grid should either be strengthened, which is traditionally done by building out with more and larger cables, *or* electricity demand – e.g. charging of EVs – should be managed intelligently to avoid large peak demands that would overload the system. The latter option is from a national economic viewpoint more attractive, since it requires less investment in reinforcements of the grid and also has other positive advantages:
- In addition to the avoidance of peaks that would strain the distribution grid, intelligent management of demand is also needed to ensure an effective utilization of wind power. Through demand management, it is possible to increase consumption when the wind blows and electricity is cheap, and to reduce consumption in calm periods. Intelligent management can also facilitate the integration and use of various storage technologies.
- A particular problem related to the integration of quickly fluctuating energy sources concerns the balancing of the grid and the avoidance of sudden drops in frequency. Smart grid investments offer possibilities for better surveillance of the frequency and voltage level in the grid and a better instantaneous regulation to avoid power outages. The costs of providing regulatory power, reserves and system services can also be reduced by letting more actors, such as local energy producers and households, participate in the provision of these services.

The main challenge is to balance consumption and production in the grid, and the basic architecture should thus consist of a combination of a power exchange highway and a data exchange highway, which enable the necessary real time dynamic feedback and interaction between e.g. households and energy producers. The smart grid has many definitions, but it can basically be understood as “the infrastructure connecting energy demand and supply using the latest developments in digital technology and communication technology in order to increase efficiency, reliability and security of the system” (Ea Energy Analyses 2010:21).

According to a report recently published by Energinet.dk (a non-profit enterprise owned by the Danish Ministry of Climate and Energy that manages the transmission net) and Dansk Energi (the Danish Energy Association), wind turbines will be able to cover 50 percent of the yearly Danish electricity consumption by 2025 (Energinet.dk, Dansk Energi 2010). By that time, Danes are expected to have 600,000 electric or plug-in hybrid cars and 300,000 heat pumps. As mentioned above, increasing electricity demand requires either a traditional expansion of the electricity grid or investment in building a smart grid. The economic benefit of choosing the smart grid solution is estimated to 6.1 billion DKK. In the analysis, the timeframe for the Danish transition is imagined in three phases, with a facilitation phase from 2010-2012 (e.g. mobilization of relevant actors, agreement on standards), an establishing phase from 2013-2020 (e.g. development of foundational platform/infrastructure), and a commercialization phase from 2021 onwards (refinement and expansion of smart grid services and solutions).

The smart grid solution with demand management differs from the present situation in which consumers are ‘passive’ or un-dynamic end-receivers of electricity, and where the load is adjusted according to their consumption practices and patterns. A smart grid is thus presented as both a more efficient and inexpensive solution to the challenges presented above (Energinet.dk, Dansk Energi 2010).

This vision enjoys support from a broad political spectrum in Denmark, from industry and NGOs. One of the arguments often brought to the fore and agreed upon by most actors is that Denmark stands a good chance of positioning itself at the forefront of the competition to develop smart grid technologies and should seize this opportunity. Certainly, many other countries share this idea of having a competitive advantage in smart grid development, relying on various positions of strength, but Denmark is already in the lead when it comes to ‘green tech’ solutions and particularly integrating wind energy in the electricity grid. The Danish electricity grid is well functioning and in many ways already intelligent. It has undergone a development from 15 central power stations in 1980 to a system consisting today of thousands of larger and smaller power-producing units, such as larger and smaller wind turbines and local combined heat and power plants.

Although most actors agree that wind and biomass are the two main renewables to rely on, there are some ‘dissenting voices’ as to the relative amount of biomass. The special-interest organization Danish Agriculture & Food Council has recently argued for a complete stop in the building of more offshore wind turbines until 2025 and instead suggests a huge expansion of the production of biogas, biomass and bioethanol – a vision that does not support the focus on an electricity-based energy system with heat pumps and EVs that is at the core of the smart grid vision.

Realising the smart grid vision is a complicated task that requires close cooperation and coordination between the different private and public actors and stakeholders. The smart grid vision still faces huge challenges in developing the ICT that can create dynamic interaction between the electricity system and consumers through monitoring, measurement, control and automation in the grid and at end-users, not to mention creation of new markets and institutional structures. This task requires that "choices are made that make sure that all actors are pulling in the same direction to avoid investments in and expenses for equipment and systems that will not be used optimally" (Energinet.dk, Dansk Energi 2010:5).

Although core actors do come a long way in aligning visions and do indeed aim to "mobilize promises about new technologies" (Pollock, Williams 2010:526), there are still some central disagreements on a very basic level. These include discussions about:

- The discourse on growth, which is important for the size of the challenge. Different emphasis is laid upon the importance of promoting energy savings in the vision, besides harvesting the other positive effects related to the management of peak loads and the effective utilization of wind energy. The right to increased growth and comfort is often presented as untouchable, e.g. that mobility should continue to grow (e.g. EVs as the family's second car). Could other less energy-demanding transport systems be advanced? The energy plans of various NGOs are relatively more focused on energy savings and changes in e.g. mobility systems.
- How much import of biomass? The available amount of biomass to back up wind energy is limited unless import from other countries is considered. The Climate Commission points out that biomass is becoming a scarce resource globally. NGOs are also arguing that the use of biomass should be restricted, because it will be competing with food production on a global level. The electric companies, however, have been arguing for import of biomass, because it extends the lifetime of their power plants, and Dansk Energi is against 'isolationism' and nationalism with regard to the biomass market.
- The relative priority given to large investments in transnational transmission cables and large investments in a national smart grid development. A thorough and dynamic connection to the European Super Grid enable a free flow of electricity between countries and take advantage of the synergies between the different national renewables – such as wind in Denmark and water in Norway. Energinet.dk is presently investing in transnational transmission cables. However, some actors argue that extended trade with other countries may result in higher and less fluctuating electricity prices and this will remove the incentive to invest in developing smart grid technologies. Others argue that they support each other and that under all circumstances, connection to the super grid is important since flexible demand and storage capacity are only relevant for a period of a few days. If the wind does not blow for weeks, the super grid is a necessity.
- Disagreements regarding the specific design of the energy system. The extent of district heating is not entirely agreed upon. The smart grid vision promotes introducing and expanding the use of heat pumps in relatively large areas, whereas the district heating sector argues for an investment in and expansion of district heating supplied by heat pumps outside these areas (Dyrelund, Lund 2010). District heating already functions well in Denmark and can exploit garbage combustion and contribute to the storage of wind energy in hot water tanks. As wind energy can be stored cheaply as heat in the district heating system, some actors emphasize the resulting lesser need for investing hugely in balancing production and consumption via the large transnational cables. The district heating system can also be developed in synergy with solar heat and geothermic energy, which would reduce the pressure on biomass resources.

Having presented the visions and discussions pertaining to the smart grid, we now turn to an investigation of the role households are thought to play in the future smart grid.

The smart home in the smart grid – an introduction

Households are to become a core component in the smart grid in the role of dynamic partners that support the energy system by e.g. being flexible in their consumption and able to store – or even produce – electricity that can be useful for the smart grid system. Their role will thus change profoundly as they change from being viewed as a load to becoming collaborators – or at least willing to enrol in a shared, interactive network.

The household's more specific roles will obviously depend, however, on the more precise implementation of the vision: e.g. what technologies become dominant; should the households become more or less engaged in the collaboration; what emphasis is laid on energy savings and so on. For the sake of simplicity, we first summarize in a short overview the many roles that households can play from a technical perspective, some of which we have already mentioned.

- The shift to renewable wind energy means that the dominant energy form will have to become electricity, which should also become the dominant energy source within the transport and heating sectors. To replace fossil energy with wind energy in the transport sector, a large share of households need to replace gasoline-driven cars with EVs or plug-in hybrid cars. Likewise, to replace fossil energy with wind energy for heating, households outside the district heating areas would have to install electricity-driven heat pumps.
- To smooth out the traditional peak loads and avoid that EVs and heat pumps add to the problem, the households would sometimes have to displace their electricity consumption to other times of the day. Moving electricity consumption over time is also relevant in order to take advantage of wind power at night or a particularly large electricity production when the there is much wind. This time shift in electricity consumption can be exercised in several ways:
  a. Activities – such as washing clothes – can be done at times of the day when excess wind can be utilized, e.g. at night, or outside peak demand hours.
  b. Additionally, some appliances can store energy for later use of the appliance itself, e.g. when there is no wind: e.g. the battery in EVs, heat pumps with storage, or

freezers that can use electricity to drop some extra minus degrees, which can compensate for periods with no electricity and thus rising temperature.

c. Moreover, some equipment can store energy that cannot only be utilized by the device or appliance itself, but can also be delivered back to the smart grid system as electricity during periods with little wind and/or high demand. The battery in EVs is an example, but as this wears out the battery, it does not seem the most relevant option in the nearest future.

- An electricity system based on wind can cause sudden drops in frequency in the grid, e.g. if the wind direction changes. To reduce this problem, households can contribute with 'regulating power': brief decoupling of appliances to prevent blackouts. This demands automation, since it needs to happen within seconds. Several appliances could contribute, such as freezers, refrigerators, washing machines, dryers, mobile and laptop chargers etc.
- Households can also play a role in saving energy and in this way minimize the challenge of transforming the energy system. Automated energy-saving solutions that e.g. reduce stand-by consumption are seen as important smart grid technologies, but visualization of consumption is also part of the smart home. A central smart grid technology is the smart meter, which besides being able to provide readings and two-way communication between households and the electric company, can also visualize electricity consumption. Being able to register electricity consumption with an appliance-specific breakdown and visualize it, the smart meter is supposed to help households saving energy (cf. above, 'The smart grid in a historical perspective').
- Finally, households can play a role by being energy producers that cover their own needs, and to some extent, the needs of others. The smart grid can allow households to send electricity back to the grid and contribute to the production of energy. Different options exist to produce electricity, such as photovoltaics, wind, and micro CHP. Other forms of micro-generation that do not produce electricity for the grid but energy for the households' own consumption include e.g. solar heat and geothermal energy. The development of active houses and micro-generation seem to be happening faster in other EU countries such as Germany and Austria. Energy production can also occur in different forms of local collaboration between households, small local industry etc.

The smart home – issues and discourses

THE DIVISION OF LABOUR – THE CONSUMER AS ACTIVE CO-MANAGER OR UTILITY DEMAND MANAGEMENT?

One of the core issues among the stakeholders with regard to the role of households in the smart grid is the question of who should manage consumption in order to provide flexibility – the consumers themselves, or the electric companies. At each end of a continuum, the core idea is that households either move their electricity consumption themselves, based on two-way communication – through e.g. a smart meter, visualization and economic incentives, such as real-time pricing – or they allow electric companies to manage their electricity consumption and household devices from a distance based on certain criteria.

Central to this division is whether the smart grid technologies should take part in visualizing energy consumption or in making it invisible – should people be expected to change practices, or should they 'feel' as little as possible and continue everyday life as usual? In other words, should the technologies "actively 'disengage' consumers from re-evaluating their comfort expectations and practices" (Strengers 2008:382).

An example of these concerns among the smart grid stakeholders as to the role of consumers is the project eFlex, which the largest utility company in Denmark, DONG Energy, is just embarking on. It aims to test how willing their customers are to be flexible in their energy consumption. They are searching for approximately 200 families that will be divided into three groups: one group with EVs, one group with heat pumps, and one group with neither. All the families are provided with a GreenWave Reality energy management system, i.e. a home gateway, and for the first two groups of families, DONG Energy has applied their own software to the GreenWave Reality system to enable demand management. DONG Energy will be able to charge the EVs and run the heat pumps, when it is suitable for the smart grid system, but the customers will be able to choose certain profiles or criteria DONG Energy can operate within. These include specific temperature ranges in the house that they are willing to accept, or certain times the EV should always be fully charged. In return, the customers are given the management system as well as an iPod to support the interface. They can also choose between receiving cheap electricity or always 'green' electricity – i.e. from wind. The third group of families can manage their own consumption and appliances through the energy system, which also provides them with detailed information on their appliance-specific consumption patterns. They are priced on an hourly basis with dynamic prices.[1]

In this way, DONG Energy is investigating, on the one hand, flexibility in demand management, and on the other, the potentials that lie in motivating people to move energy consumption themselves through dynamic pricing and feedback. The project will also illuminate another point that we elaborate on later, namely whether managing other appliances in the home besides EVs and heat pumps presents any real flexibility for the smart grid system. Put another way, they want to assess how large the 'displacement potential' of electricity consumption from smaller appliances in the home is (e.g., freezers, washing machines, chargers etc), and whether investing in the necessary communication infrastructure in the home to enable this can pay off. The potentials of managing home appliances, however, will be investigated much more thoroughly in the far larger, newly established smart grid platform iPower, which involves 10 universities and 16 companies. The project will utilize experiences from the smart home demonstration project, Energy Flex House,[2] and the test facility PowerLabDK at Risø DTU.

1. http://www.dongenergy.dk/privat/Kundeservice/kontakt_os/Pages/Vildutest-evoresnyeprodukt.aspx and interviews with DONG Energy managers.

2. The Energy Flex House is a collaboration between the Danish Technological Institute and a large number of Danish companies. It consists of two houses, one technical laboratory facility and one house inhabited by a family.

Large-scale testing of flexible demand in households is expected to be done through the project EcoGrid EU, which is the largest European real-life, full-scale testing of a smart grid so far. It is planned to commence in spring 2011 on the Danish island of Bornholm.[3] The project will integrate at least 2,600 households, which will participate with flexible consumption as a reaction to real-time price signals. Thus, the project will develop a real-time market concept to give small end-users – e.g. households and local producers – the possibility to offer transmission system operators balancing and system services in the grid. The flexible demand potentials of EVs may also be investigated through cooperation with the EDISON project.[4]

Both ways of approaching the role of the households in the smart grid enhance the use of green energy and make energy consumption more energy efficient, but the aim of letting consumers manage energy themselves and be confronted with their consumption also aims to make households more aware of their consumer behaviour and accordingly motivate them to save energy.

However, as shown in Figure 1, energy savings through home systems have been part of the smart home 'melting pot' for quite some time without really providing the result hoped for. Several trials with consumers show that any behavioural changes accomplished through e.g. feedback and visualization on displays are not permanent and that people return to their old consumption patterns after a period of about three months – regardless of the continued feedback. One suggested explanation is that the amount of money to be saved on the electricity bill is too small to motivate a permanent break with everyday life habits. Therefore, the customer should not be bothered with the hassle of engaging in the smart grid system; instead, technological automation and utility control should automate the changes and allow consumers to continue the same convenience levels and with the same habits as before.

As mentioned above, the division of labour between the households and utilities is not necessarily envisioned as black and white – an either-or situation. Rather, a multitude of ways in between could be developed to utilize both demand response, automation technologies, and consumer engagement. For example, the electronics and software company Develco and their collaborators have developed a washing machine control unit for the newly finished project, 'Minimum Configuration Home Automation' (MCHA).[5] An important part of the project was to develop and test new methods for user-driven innovation of energy management technologies. The unit – a display – communicates with the smart grid and basically consists of a green, yellow and red button, which give the consumers the possibility to programme the washing machine to start within the next 24 hours, whenever electricity is 'greenest', (green), when it is cheapest (yellow) or right away (red). The relative importance of such a solution as part of the smart grid visions is unclear, but it does seem that most of the actors in the electricity sector focus on a model or a vision in which they sign a demand-management contract with households, and in this context, the MCHA device is of less importance.

The concepts of visualization of consumption and the energy-aware consumer ideal are still very strong among many stakeholders, however, and continue to be mentioned as an element in the visions. The Danish Energy Savings Trust is especially attentive to also keeping the smart grid discourse on energy savings and conscious consumption, instead of making it purely a question of handling increased electricity consumption, spreading out of peak loads, and the integration of fluctuating renewables.

ECONOMIC INCENTIVES FOR DEMAND MANAGEMENT

Regardless of the precise distribution of roles between the households and electricity suppliers, moving demand necessitates a change in the tax and tariff structure of the electricity market that moves towards dynamic tariffs and taxes. Today, the spot price of electricity is only approximately 20 percent of the total price paid by consumers for their electricity, whereas taxes to the government and tariffs for electricity transmission amount to around 80 percent.

Taxes and tariffs are fixed, however, which means that even though customers are charged on an hourly basis and offered dynamic spot prices – and they can utilize this dynamism through ICT (e.g. a smart meter or home gateway) – the varying spot prices have little influence on the total price per kWh and result in very limited total savings. The incentive is thus small for suppliers to utilize and develop smart grid technologies and the motivation little for consumers to move consumption, unless they are large-scale customers or have both a heat pump and an EV.

It is therefore suggested that tariffs reflect the actual costs to the system of increased consumption at any given time. A working group on dynamic tariffs, led by the Danish Energy Agency, published a report in June 2010 that concludes that these changes in tariff structure are foundational to development of smart grids in Denmark (Energistyrelsen 2010).

Surprisingly, the Danish Ministry of Taxation published a report just before, which concluded that there would be no arguments for implementing smart grids in Denmark, since the nature of wind patterns do not interact well with possibilities of shorter displacements of consumption through household heat pumps and EVs (Skatteministeriet 2010). Therefore, the report also rejects the idea of dynamic taxes. The ministry has suggested, however, that the high taxes on electricity should be lowered for electricity used for heating to match the lower taxes on oil and gas. These tax cuts would not drain the treasury, since they also promote enhanced electricity consumption. The tax reduction should also include electricity-consuming radiators.

According to the report, the excess wind turbine electricity should instead be utilized in the district heating system. A new law passed in 2009 allows the district heating sector to utilize electricity to heat water tanks with electric boilers and heat pumps.

HOUSEHOLDS AS INVESTORS

A scenario with a family living in a smart home with an EV and heat pump, as well as various appliances such as a freezer, refrigerator and washing machine, which are also connected

3. The Danish partners in the EcoGrid EU project are Energinet.dk, Østkraft and DTU. Http://www.ens.dk/da-dk/info/nyheder/temaer/fremtidensenergisystem/sider/20100219temabornholm.aspx

4. The partners in the Edison project are The Danish Energy Association, DONG Energy, DTU, Østkraft, Eurisco, IBM and Siemens. The project aims to develop an intelligent infrastructure for EVs. http://www.edison-net.dk/

5. The MCHA-project is a collaboration between the Engineering College of Aarhus, the Alexandra Institute, Develco Products and Seluxit.

to the grid to enable demand management, requires relatively large investments to be made, both by households and the electricity suppliers, which could be expected to pay for parts of the ICT infrastructure as well as smart meters.

At the moment, however, some actors are arguing that what can be achieved from integrating household appliances – such as white goods and mobile and laptop chargers – into the smart grid, would provide a very small potential for flexible demand and economic savings, and that the necessary investment would not correspond to the potentials for displacement of demand, storage capacity, or regulation power.

The potentials for large electricity consumption, and thus large flexibility, lie in heating and transport. However, an earth-to-water heat pump is quite an expensive investment for a household, and the potentials for receiving a return on the investment seem relatively small at the moment. Of course, the return increases when energy prices go up, but in the meantime public subsidies may be needed. Just relying on price fluctuations on electricity to motivate such an investment may not work, because the fluctuations will be very small most of the time, only interrupted by very short periods with highly fluctuating prices (Wilke 2010).

A change in the taxation of electricity for heat, as argued above, could increase the incentive to invest in heat pumps. Since March 2010, the government has provided subsidies for households that replace their oil burner with a heat pump, and it has just prolonged the tax exemption on EVs in Denmark until 2015.

The market for heat pumps is still immature, though, and the energy efficiency and quality of the heat pumps on the market varies greatly. Danish Energy Agency has, however, made a list of energy-labeled heat pumps to guide consumers.

A big concern regarding the will to invest in smart home devices for households is also the lack of standards for just about all technologies pertaining to the smart grid. The missing standards for e.g. wireless technologies or EV charging plugs leaves consumers with many questions as to the durability of the product they are buying. Most consumers hesitate to invest in an entire smart home solution based on the zigbee wireless communication protocol; it could become obsolete in five years and be replaced by e.g. z-wave or another communication form entirely, such as the already established copper wires, wi-fi etc. However, many stakeholders are presently working for open standards.

CONSUMER CONCERNS ON PRIVACY AND SECURITY

Stakeholders are beginning to realize that in the eagerness to develop functioning smart grid technologies and systems, questions of privacy and cyber security are often forgotten. In the last few years, several comprehensive reports analyzing the security issues of the smart grid and the smart home have been produced (e.g. in USA) that warn about severe hacking risks and terror issues. Danish stakeholders such as Dansk Standard, and the white paper "Intelligent Energy System. A White Paper with Danish Perspectives" (Ea Energy Analyses 2010), also point to the potential internal and external security and hacking issues of the smart grid. However, these are issues that can be addressed in several ways. A core unit that could be vulnerable to hacking is the smart meter, which functions as the gateway between the many digital units inside the house and the exterior world. Traditionally, the smart meter has been envisioned as the unit that is to handle all dynamic two-way communication between the household and the smart grid – electricity suppliers, Nord Pool etc. However, leaving only traditional one-way meter reading of electricity to the electricity meter and instead introduce the 'home gateway' as another information hub, which can handle all communication to appliances in the household – the meter, the local energy production, and the energy network operator (Ea Energy Analyses 2010: 57) – reduces the number of exposed access points for hacking. Communication through the smart meter electricity wires may also be too slow for some of the features and services that are envisioned. Other stakeholders are calling for another solution where instead of one home gateway in the house, there are several digital ports to the household with IP addresses, thus enabling more flexible 'plug-and play' solutions for the customers. This enables a combination of products from different companies.

Another concern for households and consumers relates to the vast amount of person-sensitive digital data that a smart grid system produces. Consumer organizations are raising concerns about privacy issues and the fact that explicit data about electricity consumption and the knowledge they reveal about everyday habits can be misused by criminals or insurance companies. Information that no one is home or about sudden increases in electricity consumption – allegedly an indication of the acquisition of new commodities, appliances etc. – could be valuable to them.

A final concern proposed by actors engaged in smart grid development relates to the ownership of the data produced. Do the households own their data, do the suppliers, or do the home gateway software companies? These questions are relevant, e.g. for the retail market, in case a customer wants to shift supplier and needs to move the information generated to the new provider (Ea Energy Analyses 2010: 58).

Perspectives and implications for energy consumption

In the following, we present some of the discussions we find interesting in relation to the smart home in the smart grid and the perspectives for energy consumption.

As we write in the historical section, when investigating the possible outcomes of the present smart grid transition process, we need to keep in mind that the smart home is a melting pot with a long history of different trends and ideas. Our contention is that these different ingredients of the melting pot co-evolve and that this co-evolution will have consequences for the overall energy impact of the transition. In this section, we only deal with relatively narrow issues of co-evolution, where the smart grid aspects of the smart home directly cut across other aspects of the smart home. A deeper analysis would have to include the dynamics related to broader societal issues, such as the strong forces behind the development of the intelligent welfare home.

WHAT IS CO-EVOLUTION?

The co-evolution of trends in the smart home is not new, but has been going on especially since the 1980s, when the visions of the smart home, such as intelligent automation of household chores, gained ground. These ideas have later co-developed with home entertainment, the safe and secure home and home systems management, and energy savings. An example is the 'Electronic Housekeeper', which is a home automation console developed in Denmark in 2006. Via a touch screen, it is possible for the consumer to manage all electrical appliances in the household and visualize their electricity consumption through an appliance-specific breakdown. They can e.g. programme the console to switch off all electrical appliances when they leave the house, thus eliminating stand-by consumption, or they can programme the console to automatically enter a 'night' condition with lower temperature. Most of the buttons on the touch screen, however, have to do with possibilities to watch TV, listen to music, receive food recipes and suggestions for the best nightlife nearby, or send an alarm by sms in case of burglary.

Another example of co-evolution is the GreenWave Reality energy management system, which consists of energy management and an electricity consumption display, but also advertises for other services that could be provided to add more value to the investment. These relate to the intelligent welfare home and security, as is apparent on the GreenWave Reality website: "Our open-standards approach also provides the platform with the flexibility to incorporate future services such as home security and elderly care."[6]

The next step in the evolution comes when the home energy management system is offered in combination with demand management and connection to the smart grid. This is the case with the eFlex demonstration project, which also offers an iPod to support the management system, possibly also when away from home if wifi is accessible. An iPod has many integrated entertainment features, such as games and music, and it therefore supports the co-evolution of entertainment and demand management.

DRIVERS FOR CO-EVOLUTION

Presenting a comprehensive analysis of the drivers of the past and present co-evolution transgresses the limits of the present paper. However, some analysis can be made of the reasons for the present co-evolution.

Some of the actors eager to promote smart grid in Denmark are attentive to the difficulties that can arise in persuading consumers to play their role in the smart grid – among other reasons, due to the limited economic potential per household and the investment that has to be made in a communication infrastructure. They accordingly suggest that demand management and home energy systems in households are offered as part of other services that the consumer is willing to pay for –notably within entertainment, health, security, comfort or convenience. Parallel to the concept of 'greenwashing', this trend could be characterized as *'funwashing'*: just as or instance ICT companies try to 'greenwash' their products by arguing that they can save energy even though their main function relates to entertainment, electricity companies may try to persuade consumers to buy their 'boring' management products by bundling them with more attractive features.

Thus, as compensation for allowing electric companies to manage household electricity demand, consumers can be offered a home gateway with features like those mentioned above. They may also be offered an 'electricity subscription', which is a package of all different kinds of services and products in addition to cheaper or greener electricity. These could be an extra mobile phone to support the remote interface of the gateway – or an iPod as mentioned in the case of the eFlex project – surveillance and home security benefits such as an sms in case of burglary, convenience elements such as a preheated and pre-lit house when coming home from work, or more exotic visions such as automated plant watering or pet feeding. These extra services may also be provided by other commercial actors such as insurance companies. The expectations to commercial actors are somewhat similar to the expectations to content providers on the internet – provide a platform and someone will fill it out.

Potentially, entirely new commercial actors will enter the court, or old ones will merge, to develop new services, products and alliances. For example, EV manufacturers could offer an advantageous 'electricity subscription' to follow the acquisition of a new EV, which includes software to support entertainment, convenience, or security, such as logging driving milage or sms in case of theft etc. Or electricity suppliers could potentially move into selling EVs together with an electricity subscription. Many stakeholders compare this dynamic to what happened in the telecom industry when mobile phones replaced old landline telephones and there was an explosion of new types of subscriptions. For example, free texting and music services were offered for a fixed monthly amount, together with acquisition of a mobile phone.

CONSEQUENCES OF CO-EVOLUTION – IS THE SMART HOME A TROJAN HORSE?

As evident from the previous sections, the present co-evolution of energy management is likely to introduce more electronic equipment into the household, and they also consume electricity. Together with indirect energy consumption, the amount of energy necessary to produce and run, not only wireless technologies such as radio transmitters to be installed in all appliances, but also smart meters and home gateways as well as extra displays and mobile phones, will undoubtedly amount to something – besides depleting natural resources.

Even though the smart home electronic devices are not costly in terms of electricity consumption compared to their potential for demand management and savings, they may become part of an unsustainable development at a much more basic level. Previous studies have shown that the integration of ICT in household practices has contributed considerably to the increase in residential electricity consumption (IEA 2009, Røpke et al. 2010). In the Danish case, residential electricity consumption would have fallen in recent years without the growth in ICT: from 2000 to 2007, electricity consumption for non-ICT fell by nearly 10 percent, while electricity consumption for ICT increased by 135 percent. Part of the background is the ongoing integration of ICT into all sorts of everyday practices – also in domains where the use of ICT is less obvious, like do-it-yourself, sports and recreational activities. In addition, the integration of ICT is often accompanied by a diversification of practices. Watching television can now be done both on a TV and on the internet (Jensen et al. 2009) – a trend which may also add to direct and indirect energy consumption. The development of the smart grid and the related installations

6. http://www.greenwavereality.com/solutions/

and functionalities in the home may intensify these trends, encouraging even more integration of ICT into such practices as cooking, laundering, driving and cleaning. Although smart functions may be applied to achieve energy savings, they are also open to attending to other concerns, which may increase energy consumption.

The introduction of smart grid and smart home technologies may furthermore have the potential of creating both entirely new practices and also normalizing new expectations to comfort, convenience, entertainment, security, health care and so on. An interesting example is an ongoing Danish study of heat pumps and their ability to function also as air conditioners. There is no tradition for using air-conditioning in Danish households. However, the introduction of heat pumps in relation to the rollout of smart grids, which also have the functionality of air conditioning, may create a new household practice of cooling and new normal expectations to indoor summer temperature, and hence end up increasing energy consumption.

Contra the intentions of moving toward more sustainable consumption, the smart grid could thus support the creation of entirely new energy-demanding practices and change consumption dynamics. Smart home technologies can in effect become a dynamic that normalizes new energy-demanding practices and supports the construction of new normal expectations to comfort and convenience, entertainment, security and health care. Expectations that could be escalating (Shove 2003).

Another aspect of the normalization of higher levels of comfort is the possible construction of new normal expectations as a consequence of the demand management trials that are presently being planned in Denmark, such as the eFlex project or the 'From Wind Power to Heat Pumps'[7] project. A previous study (Strengers 2008) has argued that the demand management trials being delivered by the utilities are shaping, and being shaped by, normal expectations of comfort. When setting up criteria within which the utilities need to operate in order to achieve demand flexibility – such as a specific temperature range that consumers are assumed to accept as comfortable – this can normalize household temperatures that are actually higher (or lower during summer if the heat pump functions as an air conditioner) than would have been the case if the household were not involved in a demand management agreement with their utility company. It does not seem that any attention is given to these possible dynamics in the present development. Investigating the assumptions of the managers who design the trials in the utility companies, and the impact the demand management trials have in relation to escalating comfort expectations (Strengers 2008) is relevant in the present transition.

PASSIVE CONSUMERS OR ENGAGED CITIZENS – HOW WILL THE TRANSITION COME ABOUT?

Denmark has today a thriving wind turbine industry. The history of this development may raise another discussion that we only open in the present paper. It is a hallmark for the development of wind energy in Denmark that it was carried by public engagement in the late 1970s, partly due to the opposition to nuclear power production. Until the 1990s, most wind turbines were produced by smaller machine manufacturers and owned by local wind turbine guilds.

The visions in the present transition of the energy system is dominated by an idea that consumers should not notice the transition they are to become a part of. The assumption in the Danish debate among stakeholders is that households can be engaged as passive consumers who react to economic incentives. The visions about the role of households primarily involves a discussion of how we should develop a combination of complex technologies and a market with a pricing system that supports the right consumer choices. But the transition of the energy system may be such a great challenge that it requires a more active engagement that extends beyond the traditional consumer role. Some very ambitious local energy projects, like the one on the island of Samsø, illustrate how much a community can achieve when local entrepreneurs succeed in mobilising citizens for a common goal. As Späth and Rohracher (Späth, Rohracher 2010) emphasize, local processes can be successful when they are guided by a vision and combine the energy perspective with other core concerns, such as saving a region from economic decay. Such examples may inspire the mobilization of citizens in transforming the energy system, also at the national level.

The magnitude of the present transition could also be a good opportunity to question more fundamental assumptions regarding the way our society works, and whether elements should be structured entirely differently. As Anthony Giddens pleaded at the World Climate Solutions conference in Copenhagen in September 2010, addressing climate change, energy and consumption issues is not only a question of developing the right technologies; we also need sociological innovation and creativity. Maybe we should not only focus, for example, on developing EVs that give us better versions of the old transport system; maybe we should start thinking 'beyond the car'.

Perspectives for further research

In this paper, we have suggested that the smart home in the smart grid will co-develop with the other ingredients of the smart home melting pot, and that this co-development may have negative consequences for total energy consumption. However, we have only opened the discussion in this paper; much more work should be done in this area. For instance, more research is needed to explore further the possibly contradicting interests between smart home stakeholders in the present transition. Also the different emphasis on energy savings and flexible demand , respectively, could be investigated more systematically. This could for example be done by analyzing the discourse on passive and active houses vs. smart homes.

User conceptions among the core actors – such as planners and managers of user trials of demand management – in the energy sector or the IT sector should also be surveyed. As discussed previously, they may play an important role in creating norms for convenience, comfort and entertainment in the smart grid. We do not have the impression that this issue receives much attention in relation to the possible implications for sustainable energy consumption in Denmark.

7. From Wind Power to Heat Pumps is a collaboration between Energinet.dk, Nordjysk Elhandel A/S, SydEnergi and NeoGrid Technologies, among others. The project aims to demonstrate how 300 households with heat pumps can be interconnected to provide storage power for wind turbine energy. It will also test the consumer flexibility.

In general, consumers as study objects in the case of the smart grid are highly relevant and under-studied. Therefore, we find it relevant to study, for example, how the smart home and its different aspects – such as remote demand management, heat pumps, EVs – interact with everyday practices in households.

As touched upon in the previous section, the active role that domestic actors can play in transitions such as the present transformation of the energy system, with few exceptions (Nye et al. 2010), has not been thoroughly investigated. It would be interesting to analyze, along the lines of the discussion of energy savings and consumer engagement, the far more active role consumers – or citizens – could possibly play in *constructing visions* (that are presently dominantly articulated by actors in e.g. the energy sector) or negotiating how we should consume and produce energy sustainably in the future.

It has been beyond the scope of the present paper to assess the role consumers play in developing the smart grid visions, although we have mentioned cases of user-driven innovation of smart grid technologies through the MCHA project and eFlex. However, one way of mobilizing consumers in this transition may be to include them, not only in the development of sustainable technologies, but also in the creation of visions for the future through user-oriented future studies. Here, users, through exercises in a participatory process, could develop visions of a sustainable future. The "researchers can try to find out what the users actually want their life to be like in the future, and on the basis of this, derive the necessary technological solutions" (Heiskanen 2005: 101).

A last important object for further research concerning the active role of domestic actors relates to the points made above about local energy production, with focus on the design of the systems of provision – on local, decentralized production of energy versus non-transparency of production and consumption in large interconnected smart grids. As argued above, integrating renewable sources in the energy system in a local perspective could possibly have transformative powers that the present smart grid visions may not have. In other words, if energy production and consumption happens in local systems or communities, then households and local businesses could be more inclined to participate in and even become catalysts for the integration of renewables, even if it could mean a transformation of aspects of their lives. This is not to say that the sustainable transition possibilities in local production are only about the potential for creating mobilizing visions and desires; investigating local production also addresses how the specific system design may influence the consumption enabled by it.

What this indicates is that sustainable energy consumption and civic engagement are not just a question of the individual's attitude, behavior and choice or about efforts of 'persuading' the individual consumer to make a 'green' choice (Shove 2010), but they are also about the materiality and socio-technical dimension of life. As Shove argues, "certain forms of demand are unavoidably inscribed, for example, in the design and operation of electricity and water infrastructures and in the architecture of the home itself" (Shove 2010: 1278). In this view, social change involves not only individual attitudes but also technological artifacts and "new markets, user practices, regulations, infrastructures and cultural meanings" (Elzen et al. 2004: 1) that continuously interact and have agency. The way domestic actors interact with systems of provision and how these systems are configured have influence on our daily practices and energy consumption. Studying cases which could enlighten these considerations – e.g. cases of micro-generation in a local community as well as micro-generation in a smart grid system – could be interesting and possibly enrich or inform the present dominating visions of the smart home in the smart grid in addition to contributing to research communities concerned with renewable energy and local production.[8]

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10 Paper II

10.1 Constructing users in the smart grid – insights from the Danish eFlex project

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ORIGINAL ARTICLE

Constructing users in the smart grid—insights from the Danish eFlex project

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Abstract The smart grid is promoted as one of the key elements in a low-carbon transition in many countries. In Denmark, the dominant framing of the smart grid emphasises the challenge of integrating much more wind power into the electricity system and using electricity for heating (heat pumps) and transport (electric cars). In the process of radically transforming the electricity system, strategic system builders need to align many forces, including consumers, who play an important role in the functioning of such large networked systems. System builders need to explore, for instance, whether and how users can be motivated to be flexible in relation to moving electricity consumption over time. This paper reports on one of the first smart-grid-related projects in Denmark in which consumer aspects have been central and where potentials for flexible electricity consumption have been tested. The aim of the paper is to explore what can be learned from such experiments and which roles they play in the construction of the smart grid. In this context, the concept of the 'aligned user' is introduced.

Keywords Smart grid · Flexible electricity consumption · User-oriented innovation · Alignment · Low carbon transition

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Introduction

Facing the great challenge of transforming the energy system to a system based on renewable energy, many actors—governments, business, local authorities, international organisations—promote the 'smart grid' as an important element in the solution. In general terms, the smart grid implies the application of information and communication technologies to make the electricity system 'intelligent' in an effort to ease the integration of intermittent energy sources like wind and solar power and to improve energy efficiency. In more specific terms, the meaning of the smart grid differs between countries, depending on the specific combination of energy technologies and the organisational set-up of the energy systems; and sometimes, different national actors frame the smart grid in different ways, in relation to their particular perspectives. This paper deals with the smart grid issue in a Danish context, where the dominant framing presently emphasises the challenge of integrating much more wind power into the electricity system, and using electricity for heating (heat pumps) and transport (electric cars).

When new provision systems are constructed and when old systems are radically transformed, many forces have to be aligned. To some extent, the alignment can emerge without active and conscious coordination, but usually some actors play the role of strategic system builders. As Hughes (1983) has described, the early system builders of the power system were aware of the need to interconnect a large number of diverse components into a seamless web—physical artefacts, utility companies, manufacturing firms, academic research and development laboratories, investment banks, regulatory authorities, consumers, etc.—to realise their visions. Surely, this is also the case today in relation to the smart grid. During the last few years, many actors within business, research, and government have made a considerable effort to promote the idea of a smart grid in Denmark, culminating in the political decision to finalise a plan before the end of 2012 on how to implement a smart grid. Until now, system actors have concentrated on providing reports on the advantages and challenges related to the smart grid, and on initiating technical research and demonstration projects (Energinet.dk, Dansk Energi 2010, Ea Energy Analyses 2010). In addition to technical and economic issues, the reports emphasise the need for exploring how electricity consumers can be motivated to play their potential roles in the envisioned system and how business models can be constructed that combine consumer motivation with the business interest in earning a profit. In only a few cases do the research and demonstration projects include studies on consumer aspects, but this is about to change, since more studies involving users are planned for the near future. In this paper, we report on the eFlex project, one of the first smart-grid-related projects in Denmark in which consumer aspects are central, and discuss what can be learned from such projects and which roles they play in the wider construction of the smart grid.

It can be argued that all products and services, and thus all innovations, are integrated into larger systems of provision and use, but this is particularly evident when it comes to innovations in relation to large networked provision systems like the electricity system, where consumers play an important role for the functioning of the system. In the formulation by Shove and Chappells, householders are not just consumers of, for instance, electricity—they own 'the sensitive fingertips of existing infrastructure', such as wires and contacts, ground fault circuit interrupters, routers and switches, and all the electric appliances in the home, which are literally part of the infrastructure itself; householders are thus co-managers who are implicated in the routine functioning of the system as a whole (Shove and Chappells 2001, p. 57). Already in the early history of the electricity system, it was a challenge for providers to encourage consumers to behave in ways that fit better with system demands. The nearly exclusive use of electricity for lighting caused high peaks and long periods with low demand, implying ineffective utilisation of generating capacity. To even out demand, utilities thus actively promoted the use of electric appliances. The period of manufacturing demand was followed by a period of meeting demand: After the Second World War, electricity consumption grew rapidly along with economic growth, and the challenge for utilities was seen to be 'predict and provide'. This gradually changed when the environmental agenda emerged and questioned the societal rationality of an ever-expanding system, which also required large investments. Rather than just meeting demand, the concern for managing demand became more pressing. In a Danish context, the focus was on energy savings (e.g. labelling appliances and prohibiting installation of electric heating in new houses) and promotion of combined heat and power production (involving a duty to connect). The interest in reducing or shifting the peak through demand management came much later in Denmark than in many other countries because the transmission and distribution grids had been constructed with considerable excess capacity. But now, the time has come to focus much more on demand management as an integral part of preparing the functioning electricity system for the future.

The present interest in exploring and defining user roles in relation to the establishment of a smart grid has emerged within a contemporary context in which user involvement and user-oriented innovation is popular. Studies or direct involvement of users in relation to innovation projects can be motivated by various considerations. When a new product or service is offered, it is obviously important to assess whether it will have a market, whether consumers can be segmented in different groups, and what price these groups are willing to pay. It is typically a task for marketing departments or consultants to consider such questions, which may also include the desirability of various product features. There is a long tradition for such marketing studies, where methods usually include questionnaires and focus groups. Users may also play a direct role in the innovation process by testing prototypes or providing ideas for product developers. As emphasised in various strands of the literature, users have never been passive recipients of new technologies, but contribute to their development through 'learning by doing', 'learning by using', and 'learning by interaction', which provides more qualified feedback on user requirements than market transactions, and processes of domestication. However, feedback from early users has often been part of the diffusion process—that is, after the initial product launch. Increasingly, such feedback is organised to be included earlier in the development process through cooperation with lead users (Von Hippel 1988) or through experiments, tests and discussions with ordinary users (Heiskanen et al. 2005, 2010). In the case of lead users, they are expected to have a personal interest in the development of a particular product and to be competent advisors for developers, able to point out fundamental problems and assist with technical knowledge. Some also argue that lead users represent needs that are 'ahead of the market' and thus anticipate the demand of future consumers later in the diffusion process. The interaction with more ordinary users is expected to support the alignment of user practices and design options: User interests cannot be identified in advance, but have to be constructed in relation to the technical options.

Sometimes, product developers cooperate directly with users, while in other cases, professional mediators are involved in the process. Schot and de la Bruheze emphasise the importance of mediators in the process of mutual articulation of demand and supply and introduce the concept of mediation junction as 'the place at which consumers, mediators, and producers meet to negotiate, articulate, and align specific technical choices and user needs' (Schot and de la Bruheze 2003, p. 234). Their conception of mediators is broad and includes all sorts of associations related to specific product groups (e.g. auto clubs), more general consumer organisations, marketing and testing agencies, retailers and groups of academics and consultants who claim to provide knowledge on consumer interests. Mediators take on the task of bringing 'represented users' into the process, in addition to the 'projected users' whom innovators and designers try to inscribe in their products, and the 'real users' who become involved sooner or later. In relation to user-oriented innovation, it has become popular to include anthropologists as mediators, since they are considered to have particular skills in accessing and interpreting the world of users (Suchman 2013). The case study for this paper exemplifies this trend, since anthropologists are involved as mediators.

The case study is based on participatory observation. The first author cooperated with the anthropologists in the eFlex project, carried out some of the field work and participated in analysing the empirical data. This provides the basis for both reporting on key results of the eFlex project and for broader reflections on the role of such a project. Informed by the literature on the role of users in systems and in innovation processes, the following research questions are explored:

- What kinds of learning can the system builders obtain from such experiments?
- Do the experiments serve other purposes than learning?
- Which roles are assigned to the users in the experiments?
- Which roles do the mediators play in the process?
- In which ways can such a project contribute to a low carbon future? Can the project be counterproductive in relation to this aim?

In the following, we provide first a little more background on the Danish context for smart grid experiments, and then we present the case study: the purpose of the eFlex project, the methods applied in the project and the results. In the final section, we discuss the research questions in relation to the learning achieved through the project, other roles of the project and the implications related to a low carbon future.

The Danish context: two interacting system transformations

The smart grid transformation of the electricity system develops in interaction with the process of liberalisation of the electricity trade, which was set in motion by EU's market directives in the 1990s. In Denmark, consumers have been able to choose their electricity supplier since January 2003. Production and trade in electricity have been separated from transmission and distribution, which are natural monopolies. The transmission net is run by the state-owned company Energinet.dk, which has the overall system responsibility, while the distribution nets are owned by about 70 grid companies (2012), regulated by The Danish Energy Regulatory Authority (DERA). About 75 % of the wholesale trade in electricity takes place on the Nord Pool Exchange (owned by the Nordic companies with overall system responsibility), where producers from all the Nordic countries (and Germany, UK and Estonia) sell electricity to traders and to firms using more than 100,000 kW h/year. The retail market is still nationally organised, but a Nordic retail market is being pursued.

Although nearly 30 traders sell electricity to Danish consumers and smaller firms, competition in the retail market is considered to be limited (Konkurrence-og Forbrugerstyrelsen 2011). With liberalisation, each of the former local monopolies was transformed into a group composed of a regulated grid company and a commercial trader, and the trader was assigned the obligation to supply customers in its old area for a fixed price set by DERA if customers did not actively choose another supplier. Nearly 10 years later, 83 % of the small customers still buy price-regulated electricity (p. 14); traders with the duty to supply usually have about 90 % of the customers in their own area (p. 17), and only 6 % of consumers have changed supplier during the period 2008–2010 (p. 22). One reason is probably that there is little to save by changing. Due to taxes and tariffs, the supplier's electricity price constitutes a small part of the electricity price for consumers. Furthermore, the scope for competition is limited by the fact that small customers pay a fixed price per kilowatt hour, independent of the consumption profile during day and night (p. 15). Suppliers are thus not allowed to offer hourly payment that would give consumers the opportunity to save money by shifting consumption over time. A third reason relates to invoicing: When customers buy electricity from a trader affiliated with a grid company, they only get one invoice. In other cases, customers receive separate invoices from the trader and the grid company, unless the trader makes cumbersome arrangements with the grid company (p. 15). Finally, electricity is a low-interest area, and due to the supply obligation, consumers do not even have to bother with delivery.

These conditions are about to change due to the combined pressure from continued market liberalisation and the smart grid challenge. A new model for payment (called the wholesale model) will be implemented, probably in 2014, in which consumers will only be customers of the trader and no longer the grid company. The grid company then becomes a wholesaler selling the distribution service to the trader, and the consumer will receive only one invoice. Change of supplier is also expected to be eased in March 2013 by the establishment of a so-called DataHub, where all data on electricity consumption will be gathered to simplify communication between market actors and reduce entry barriers. The process towards hourly payment is also on the way. The first condition is the installation of remote meter reading on an hourly basis. More than half of Danish households either have or will have remote metering in the near future, installed by the grid companies, and political intervention can be expected to bring this up to 100 % within a few years. Remote metering and payment on an hourly basis combined with the possibility of managing demand—smart metering—is the key to involving consumers in the smart grid.

The smart grid appears both in relation to the overall management of an energy system based on intermittent energy sources and in relation to demand management at the household level (also at the business level, which is not the focus here). The need for demand management occurs for several reasons. First, the expected increased use of heat pumps and electric cars may add to the traditional peaks in electricity consumption and thus create local overload in the distribution grids. Since extensions of the grid are very expensive, cost–benefit analyses indicate that considerable savings can be achieved by investing in a smart grid that enables demand management (Energinet.dk, Dansk Energi 2010). Second, storage capacity in households may provide outlets for abundant wind power, and third, households may provide short-term regulatory services. The most immediate concern is the avoidance of increased peak loads—an issue that is particularly important for the grid companies, which are responsible for strengthening the grid.

The interest in electricity consumers in relation to the smart grid and smart meters thus emerges from various perspectives. For instance, while grid companies focus on the avoidance of peak loads, electricity traders face the challenge of profiling themselves in relation to customers by developing brands and differentiated services in spite of selling exactly the same basic product. Simultaneously, there is a societal interest in encouraging energy savings and changing the mix of energy sources. This variety of interests is worth keeping in mind when studying concrete examples of smart grid projects involving users.

The eFlex project

Purpose

DONG Energy (in the following DE) is one of the leading energy groups in Northern Europe with headquarters in Denmark. The company procures, produces, distributes and trades energy. Since the financial crisis put a stop to the process of privatisation, the group is still a public limited company with 76 % of the shares owned by the Danish state. The eFlex project is based in the 'Sales & Distribution' division, which consists of two separate companies—'Sales' and 'Distribution'—due to the liberalisation of the electricity market. The project was commissioned and paid by 'Distribution', which owns and operates the distribution electricity grid in Copenhagen and Northern Zealand, but daily management of the project resided in the Grid Strategy Department, a technical unit under Sales & Distribution that was hired as consultants by Distribution.

The electricity distribution companies are faced with the scenario that Danes will have welcomed 300,000 heat pumps and 600,000 electric or plug-in hybrid cars by 2025 (Energinet.dk, Dansk Energi 2010). The eFlex project was initiated as an attempt to understand what it takes to make consumers move their electricity consumption to other times of day to avoid escalating peak loads and huge investments in expanding the distribution grid. To 'make consumers play along' and engage in a 'partnership on peak shaving', they have to be motivated, and since few households take much interest in their electricity consumption, DE Distribution expected that consumers' price sensitivity might be relatively low. Therefore, DE Distribution aimed to explore what other incentives for flexibility were in play and how these could be mobilised in the change process. To investigate this, DE Distribution hired antropologerne.com, a small consultancy company working with user-oriented innovation, service design, organisational development and communication. The consultants were to conduct a user study that supported the other more technical part of the eFlex demonstration project—the testing of new smart grid prototype technologies for demand management of electric vehicles, heat pumps and domestic appliances in a number of households in DE's distribution area. Antropologerne.com was hired to investigate the assumption that customers' price sensitivity and their motivation for moving electricity consumption—aided by the new smart home equipment—would be strengthened if they developed a new relationship to their electricity company and to electricity as a product.

The Grid Strategy Department is responsible for grid planning with regard to improvements (automation), maintenance and investment planning. Their main interest in the eFlex project was to assess the 'flexibility potential' of the households, i.e. how much electricity consumption could actually be moved away from peak hours—could they *count on* customers' flexibility and *calculate when, where, how long and how much* they would be flexible. They were primarily interested in customers who had either a water-to-water or air-to-water heat pump or an electric vehicle, as especially these two technologies are expected to contribute to peak loads in the future. The anthropological user study was expected to identify the unknown 'human' parameters, such as 'flexibility-readiness' and 'acceptance of supply interruption' in a complicated equation of the household flexibility potential. This equation would, e.g. include knowledge on the m2 of the house, kilowatt hour consumption, heat pump or not, insulation degree and building year. The Grid Strategy Department was also concerned with how to categorise customers in different segments—i.e. what consumer types seem to be very flexible and what characterises consumer segments that are not. The hope was that these insights would also provide knowledge on where DE distribution could geographically postpone investments in the distribution grid and where not (Torntoft Jensen 2011, p. 48). On the basis of these interests, the project manager of eFlex and antropologerne.com, together, wrote a project design document describing antropologerne.com's deliveries. These included among other the development of flexibility profiles of the users (segmentation), an evaluation of the test equipment, a mapping of 'energy behaviour' and appropriation of equipment, identification of motivational factors for energy flexibility and an evaluation of the 'flexibility promoting potentials' of different communication forms with the customers.

Method and framing of the eFlex project—the GWR equipment

One of the basic elements in the project design was the testing of a home automation energy management system (Fig. 1), which the company GreenWave Reality (GWR) had developed for DE based on a previous user-oriented innovation study by the Alexandra Institute (Alexandra Instituttet 2010). The equipment was included in the project on the

Fig. 1 The GWR equipment (image from antropologerne.com)

assumption that visualisation of the customers' appliance-specific consumption and a new communication interface with DE would provide the information, awareness and interest needed to encourage flexibility—as well as provide the ability to automate the moving of consumption conveniently.

The kit that participants received and installed in their houses consisted of a main unit called a 'gateway', which is connected to the internet. The gateway communicates wirelessly with a number of intelligent power nodes that are controllable plugs with on/off control. The users could control the gateway and thus the power nodes via an online 'portal', which they accessed from either a computer or from an iPod Touch. Thus, if the users connected the power nodes to appliances around the house, they would be able to see on the portal how much power each appliance consumes throughout the day. They could turn them off from the portal, or they could program certain power nodes to turn off or on collectively at specific times of the day, and thus make e.g. an 'out' profile, or 'sleep' profile'. Moreover, the participants agreed to transfer to hourly pricing, which follows the spot price on the Nord Pool market, and they were also offered variable distribution grid tariffs (requiring special permission for this project). Accordingly, the next 24 h' dynamic prices, which were visible on the portal, and which the customers were priced after, were based on a combination of dynamic spot prices and variable tariffs and could differ between 1.50 kr (0.20 €) per kWh to 4.30 kr (0.58 €) per kWh. Hence, the users could utilise this information to construct certain profiles or turn devices on/off individually at certain times in periods when the price is low/high.

The project design included a group of households with a heat pump, a group of households with an electric vehicle and a 'control group' of 'ordinary' households without either. All three groups had the energy management system just described. In the heat pump group, DE could reduce consumption—or 'optimise'—the heat pump externally, and this group had an extra feature on the portal they could use to follow DE's interaction with the heat pump. The participants had to indicate which minimum temperature they would accept in the home and where on a scale from 'low' to 'high' their 'flexibility level' was, which meant that the heat pump could be disconnected for periods of 1–3 h. Likewise, the charging of the electric car batteries was controlled externally by DE. The users had to specify through the portal at what time in the morning the battery should be ready and charged and its minimum percentage level. Moreover, the users also had to tick off whether they prioritised consuming electricity at the lowest price, or at a time when the share of wind energy was highest in the grid's energy mix, or a balance of these alternatives. Based on the information of minimum room temperature, the choice of flexibility versus comfort, the prioritisation of price versus wind and the daily price pattern (the el spot market is a day-ahead market), an algorithm calculated the period and

Table 1 Project design

	Loop 1	Loop 2	Loop 3
Households included in the trial (in total 119)	29 ordinary households 26 heat pump owners	9 electric vehicle owners	55 heat pump owners
Number of households interviewed	16 ordinary households 6 heat pump owners	9 electric vehicle users 3 heat pump re-visits from loop 1	15 heat pump owners
Field work period	March, April, May 2011	September, October, November 2011	November, December 2011, January 2012

time of heat pump interruption and downloaded the results to each households' gateway for in-house control.

The user study was divided into three 'loops', each including a round of fieldwork and preliminary analysis (Table 1).

Recruitment Participants for the study were recruited through DE's newsletter or were contacted directly, e.g. if they were already involved in another project called 'control your heat pump' led by Energinet.dk. Antropologerne.com recruited the electric vehicle households through their own network and with the help of the Danish Electric Vehicle Committee. Participants were required to reside in DE's distribution area and consume more than 4,000 kW h/year. They were offered 1,000 DKK to participate in the trial and were also allowed to keep the equipment including the iPod after the trial had ended. DE originally looked for approximately 50 households with an electric vehicle, 75 households with a heat pump and 30 households without. It turned out, however, to be very hard to find that amount of electric vehicle owners in DE's distribution area.

The eFlex pilots The eFlex participants' homes were distributed evenly over DE's entire supply area, which covers a large part of mid- and northern Zealand. Of the 119 official test pilots—i.e. the main contact persons in the households—103 were men, mainly 40–59 years old, and a majority had families with two or more children. It was emphasised that the project included the household as a whole and not only the test pilot. The participants were also among the more well-to-do segment of the Danish population and often lived in detached or semi-detached houses. Their dwellings were often large, i.e. 100–250 m^2 and most participants consumed 7,000–15,000 kW h/year; some were also above 15,000 kW h. The eFlex pilots generally had a high education, and many of them were trained as engineers or economists or worked within IT.

Fieldwork—empirical data

In total, the empirical data included 49 household visits, debates on PODIO, notes from different information events for the households, two user workshops, three analysis workshops with DE's Team eFlex at the end of each loop, questionnaires on demographics and lifestyle issues and a 'choose-a-profile' exercise[1] (Table 2).

Results

We include first a short summary of the technical results before presenting some examples of the experiences and observations from the householders' everyday life with the eFlex project and finally the conclusions from the user study.

Results from grid analysis

DE expects to publish a main report on both the technical and behavioural findings from the eFlex study in autumn 2012. Results of the technical part of the project offered here are from the preliminary analysis presented at a final conference for the eFlex project in March 2012. The results only concern the heat pumps, as the measurements from the electrical vehicle group were not usable for any statistical purposes, since there were only eight participants (one resigned from the project

[1] The first author of this article conducted 11 of the 49 household visits and participated on PODIO, in workshops and in internal meetings with subsequent analysis sessions. The final work with the results and writing of the report was done solely by antropologerne.com.

Table 2 Analysis was based on a broad range of field material

House-hold visits	Each visit lasted four to five hours and included interviews, lunch or dinner with the families as well as a 'grand tour' of the dwelling. Parts of the interviews and use situations were video recorded and photos were taken of the user and the family, the dwelling, symbols of life style, the GWR equipment and the heat pump or electric vehicle, etc.
PODIO	PODIO is a social media platform that combines text, images, video, etc. It functioned as a project management tool by which antropologerne.com, DE and the users could communicate and share experiences. Of the 119 eFlex pilots in the project, 114 of them registered on PODIO during the project
Arrangements	Several events were held for the participants – among them a 'futures night', where the then CEO at DE, Anders Eldrup, came to talk to the participants about their important role in the future electricity system. Moreover, three information events before each loop were held, and a 'question night' in loop 1
Workshops	A number of 'analysis and user workshops' were conducted after each loop in which preliminary findings were discussed with DE as well as with the users. The users participated in two user workshops with focus group exercises and interviews while three workshops were held with DE's Team eFlex
Questionnaires and choose a profile	A questionnaire on lifestyle and demographics was answered by 97 of the 119 participants. Moreover, all 119 users in the project were asked to place themselves in one of five user profiles that were constructed on the basis of the 49 household visits and a user workshop with 8 eFlex participants. 72 participants chose to do so, and the results were correlated with the results from the questionnaires

before time), and since it turned out that many of the vehicles were of a too-old model to be able to work together with the technical equipment. Optimisations of the heat pumps generally took place between 7 and 9 AM or 5 and 7 PM. Interruption of the heat pumps depended on the flexibility choices (see earlier description), the house's thermal behaviour and the household's 'living habits'. In periods with outdoor temperatures ranging from −15 to −5 °C, 65 % of the heat pumps were still shut down after 1 h, but this declined to 7 % after 2 h. With outdoor temperatures ranging from 5 to 15 °C, the same figures were 85 and 35 %—i.e., the colder the weather the less interruption of heat pumps was possible.

Two interesting conclusions could be drawn from the technical analysis. The interruption period tends to be too short compared to an average peak load in the grid, which indicates that heat pumps may need to be cascade controlled to 'last' an entire grid load. Secondly, the expected 'kick back' from releasing heat pumps to normal operation was not very clearly observed, although it was there. Since users' 'living habits' in terms of using wood-burning stoves, opening windows, having guests, cooking, dressing, etc. had a significant influence on heat pump operation patterns, the interpretation of results was difficult.

Finally, the 'control' household group, which only had the GWR equipment, had on average saved approximately 10 % on their kilowatt hour consumption during the project period March 2011 to February 2012. This finding is consistent with other studies on the effect of visualisation of energy consumption and feedback, which suggests that energy consumption can be reduced by 5–15 % depending on the kind of feedback provided (Darby 2006). A recent large study from the UK suggests that the top of this range may be far too optimistic and underlines that the savings that can be achieved through feedback vary greatly depending on period, customer group and type of energy (e.g. electricity or gas) (Raw and Ross 2011). The effect of feedback through the portal was not calculated for the other two groups, as DE wanted a 'pure' evaluation of the effect of the GWR equipment without the possible influence from also having a heat pump or an electrical vehicle.

Experiences and observations: everyday life with eFlex and use of GWR

In the final report, antropologerne.com organises some of the findings by applying the four phases of domestication theory: commodification, objectification, incorporation and conversion (Berker et al. 2006). The idea is to consider the home automation equipment and the related services as a 'wild animal' that households try to domesticate. We must leave out many details in the description of the domestication process here in order to concentrate on a small selection of topics in two key phases. In some cases, we draw on examples from the first author's interviews.

The first steps

In relation to the objectification process—the concrete physical placement of the GWR equipment—some participants faced integration problems. Setting up the equipment was a task for technical enthusiasts, and for many, it was a challenge to configure the power nodes on the portal. A specific problem at the project's start was that the power nodes had no ground connection, which meant that devices such as dishwashers, washing machines and tumble dryers could not be connected. This was unfortunate since these household appliances consume much electricity and involve a form of consumption that actually could be moved. The problem with ground connection was later solved, but many kitchens also have in-built appliances with power plugs that are not readily accessible anyway.

For some participants, the placement of the nodes was also a challenge, and it was unclear whether the home energy management system could really support flexibility. One participant, for instance, walked around the house to find devices to plug into a power node but concluded that most of the devices that could be plugged into the power nodes—e.g. lamps, TV's, kitchen appliances, etc.—were devices you had to use when you had to use them. Similarly, some participants argued that it would be too troublesome to postpone, e.g. vacuuming or working on house renovations with power tools to other times of the day when they might not have the energy, 'inspiration' or time.

For heat pump owners, the set-up involved particular decisions. A little more than half of the 81 heat pump users chose the price optimisation of heat pump operation, while the rest chose a combination of price and wind content optimisation. Only one participant chose a pure wind content optimisation. However, the wind content optimisation resulted in heat pump interruption that was difficult to understand. Because wind energy was often low at night, many heat pump interruption programmes were set for interruptions at night and not during price peak hours. Balance between price and wind energy content was complicated to find, and indeed to communicate to customers, and over time, more and more participants readjusted to pure price optimisation. Many also chose the maximum heat pump flexibility level, i.e. allowing DE to reduce electricity consumption for the longest time. The participants chose everything between 16 and 20 °C as the lowest acceptable temperature in the dwelling, but the majority maintained the default value of 17 °C as the minimum room temperature and a comfort temperature around 21–22 ° C.

Common applications

In the phase of incorporation, when the GWR equipment is incorporated into family practices, many participants concentrated on using the system in order to get an idea of their different devices' consumption—e.g. the cost of brewing a cup of coffee. They were looking for the greatest electricity consumers and were surprised at how much the children's play station and fish tank or their hard disk recorder consumed. Consequently, they developed a new habit of turning items off manually or through profiles when not in use, despite the hassle of having to wait for the TV to warm up again, because it was completely disconnected at the power node. The equipment also showed when during the day or night electricity was cheap or 'green' and when to avoid expensive tariffs. Accordingly, many participants utilised their washing machine's or dishwasher's old fashioned time delay mechanism and consistently postponed doing their laundry until the weekends or nights, when tariffs were lower.

Moving laundry and dishwashing to nighttime seemed to be the most frequently changed activity for participants in the eFlex project. Most had also plugged in some appliances into the power nodes—usually lamps, TV sets, computers, internet routers and gaming consoles. Moreover, some eFlex pilots plugged in chest freezers, refrigerators or electrical heating in bathroom floors and made profiles that turned them off during certain periods of the day. Some participants explained that once they had 'played around' experimenting with connecting and configuring the power nodes—or once they had given up doing this—and started postponing, e.g. the washing machine and dishwasher to nighttime, their commitment and activities related to the project decreased.

Flexibility in the family context

Domestication processes proceed differently depending on family structures. This has implications for flexibility. For instance, households consisting of singles or couples with no children or pets are often more flexible in their habits and electricity consumption and, e.g. more willing to compromise on their comfort, than families with (small) children or pets. As one retired couple explained, when the grandchildren were visiting, they were less prepared to keep a low temperature in the house and put on a sweater, especially because the smallest grandchildren crawl on the floor. Another mother resisted the idea of washing at night because she was concerned that the noise would wake up her teenage son, who had a room in the basement not very far from the washing machine. Yet another participant was, e.g. upset that his aquarium fish had 'been up all night': due to a malfunction the light in the fish tank had not been turned off by the GWR nodes. In general, families with children have a tightly coordinated everyday life, which means they have less flexibility potential. As a father of two explained, it was hard to be flexible with, e.g. doing laundry, because the boys' soccer clothes had to be dry and ready for training and games at certain times.

In some cases, the eFlex project gave rise to tensions within families. Several wives of enthusiastic eFlex pilots were irritated because their husbands demanded that they suddenly start running the dishwasher or washing machine at night. They were concerned that the clothes would be wrinkled from lying in the machine all night and that the machine would have to be emptied in the morning when they had to help the children get ready for school. Some wives also found the GWR equipment ugly; it did not fit very well into the interior decoration; they could not clean properly or they could suddenly not turn on the TV or brew coffee for their guests because their household appliances were connected to the power nodes. These nodes would turn off at random or they did not know how to control/manage them with the iPod. In another family, the teenage children were obviously annoyed with having their electricity consumption supervised and controlled by the father who would check on the iPod, which he brought to work, whether they played on the computer in the afternoon when they had promised to walk the dog or he would turn off their computers through the iPod, if they played games past bedtime.

Complex user behaviour

The project gave rise to several findings that illustrate the complexity in the interplay between the company and the users in relation to flexibility. In the context of heat pumps, for instance, many owners also heated their dwellings with other heat sources, like fireplaces or wood-burning stoves, which increased their flexibility potential. Some of the participants wanted the heat pump to be turned off for even longer than was actually part of the project design because they could just use the fireplace if the temperature dropped noticeably. Thus, a participant with a large buffer tank and a fireplace was disappointed that he could not save even more from being flexible with the heat pump than the project actually allowed, and he explained that they never 'felt' the optimisations. In general, the participants experienced very little comfort loss from the optimisations.

In a few cases, participants were interested in taking control themselves or redesigning the system. Some had joined the project to 'sniff' at the smart grid development, while others engaged in 'system design' on a more micro-level. One of the electrical vehicle owners—a young man trained as an electrician—had also tampered with and rewired the power nodes himself to give them a ground connection so he could plug in his refrigerator and freezer and start experimenting with flexible profiles. Another participant proudly proclaimed: 'DONG control—I over-control'. He consistently turned off—or optimised—his heat pump for longer times than DE. He set his heat pump to an indoor temperature of 27 ° C in periods with cheapest electricity because he could store the excess heat produced in his buffer tank and accordingly turn off the pump for long periods during the day, when electricity was most expensive.

Conclusions—four main findings in eFlex

In the final user study report (antropologerne.com 2012), which did not include grid analysis, antropologerne.com sum up their results in four main conclusions.

Flexibility and innovation In a project like eFlex, the future is investigated at the same time as it is created. eFlex is thus not just a question of testing new technologies and uses, but also a question of rehearsing new relations and creating cooperation, learning and understanding with the customers. DE has not only learned about the customers, but also from and with the customers.

Electricity is life Electricity is used to create life in the home. It is used for both necessary household practices like heating and for more 'luxurious' practices that are important for identity formation, such as hobbies and social life. Households seemed most willing to be flexible with regard to necessities, while they expressed a need to justify and legitimate hobbies, for instance, by referring to environmental friendliness.

Motivation The user study resulted in several insights concerning motivation for flexibility:

(a) Flexibility potential: The user study identified the four factors below (Fig. 2), which in practice play a role for household flexibility potential. Customers “must be reached differently through diverse messages, concepts, products, services, interfaces and communication forms” (antropologerne.com 2012, p. 39) to realise the potential.

- Willingness to flexibility: The participants' willingness and motivation to move consumption is dependent on their general interests, attitudes, values and comfort habits, as well as their relationship to technology, economy and the environment.
- Family composition: Flexibility depends on the composition of the entire household. Care for the wellbeing of, e.g. children or pets often leaves the participants less willing to compromise comfort or convenience or to change daily habits and structures.
- Life situations: Interest in electricity consumption and flexibility can be triggered by change in life circumstances—e.g. moving from a flat to a house, acquiring a new electricity-consuming heat pump, refurbishment of the house, engagement in new hobbies or transition from working to retirement.
- Household infrastructure and smart technologies: for example, degree of insulation, floor heating, buffer tanks and fireplaces in the home as well as smart home systems that can automate moving consumption all influence flexibility potential.

(b) GWR equipment is a missing link and promotes flexibility: GWR equipment becomes a link that connects daily practices with the electricity consumption of the household. It creates a tangible connection to the electricity world and motivates the participants to be flexible, both by enhancing their interest in electricity consumption and providing them with the tools to know what devices to turn off or which practices to intervene in.

(c) Economy as motivating factor: The participants are driven by multiple economic rationales, including a ‘moral economy’ promoting the wish to do what is right and sensible—such as avoiding waste and optimising consumption. Variable prices and tariffs support this ‘feeling of doing right’. The participants do not necessarily know precisely how much they save when moving consumption; they just know that they should consume when the price is low—in effect making the price also a signal of right and wrong.

Five user profiles are identified The user study resulted in five user profiles, which fall in the two main categories of ‘the enthusiastic’ and ‘the interested’. The participants were segmented according to their use of the GWR equipment in the home, their life values, professional background, knowledge of and relationship to ‘the electricity world’ and their motivations for being a part of eFlex. The different user profiles are motivated to participate in the project and to provide flexibility for different reasons. Moreover, different communication strategies apply to each profile. For example, ‘the technical’ are greatly motivated to use the portal and PODIO to discuss technical issues with other users and DE, whereas the eFlex application for the iPod and information events are appealing to ‘the comfortable’.

Enthusiastic:

- The *technical*: technique-enthusiasts who are engaged in the ‘electricity world’; they have joined eFlex to contribute to technological and societal development
- The *economical*: system-thinkers who have joined eFlex to control and optimise the family's energy consumption
- The *curious*: people with an inquiring attitude toward life; for them, eFlex is an opportunity to learn new things about energy and electricity.

Interested:

- The *participating*: humanists who want to do something good for others; they are primarily in the eFlex project for the sake of the environment and the project's greater cause
- The *comfortable*: appreciate comfort and convenience in their homes; for them, eFlex is an opportunity to save money and do a good deed without compromising comfort or time for other things.

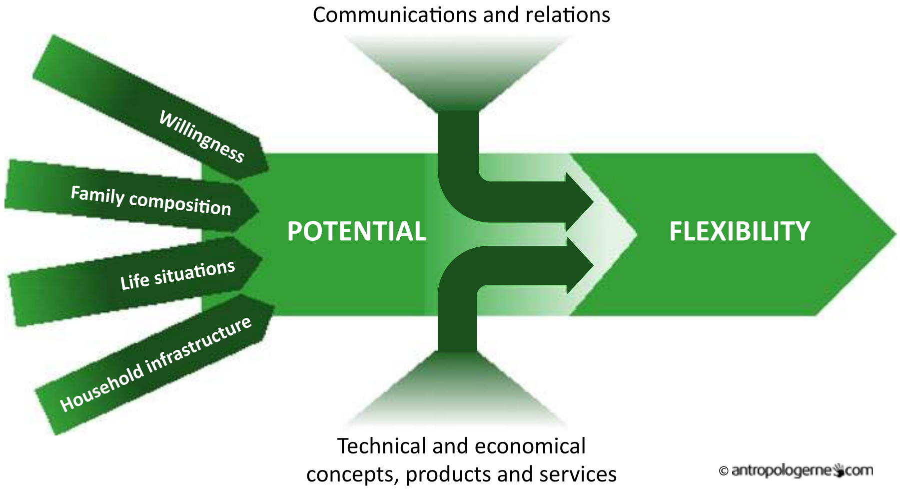

Fig. 2 Several factors have influence on flexibility (image from antropologerne.com)

Discussion and conclusion

Complex knowledge interests

On 7 March 2012, more than 150 people from the business sector, research, media and policy making, including the Minister for Climate, Energy and Buildings, the Vice president in DE and the director of the Danish Consumer Council, attended the conference reporting on eFlex results.

Considering all the hype surrounding this event, the project would seem to have been a great success, but a critical look at the course of the project reveals that the design and knowledge outcomes were challenged by having to accommodate many different actors' knowledge interests. The many expected insights to be delivered—the household's flexibility potential, 'energy behaviour', economy vs. new relations as motivator for entering a partnership with DE, usability of the GWR equipment, etc.—resulted in an interview guide for loop 1 that covered ten themes and a large number of exercises to fulfil the in total seven deliveries agreed upon. From a social science point of view, this conferred a breadth to the interview guide that resulted in shallowness in the findings. Moreover, although Distribution's main interest was in flexibility for heat pumps and electric vehicles, there was relatively little focus on these technologies in the field manual design. Relevant knowledge of the extent of householders' heat pump and electric vehicle flexibility would require thorough studies of heat comfort and mobility practices. Instead, the field manual focused a great deal on communications and relations, attitudes, values and motivations for flexible electricity consumption in general—which is not very surprising, since DE formulated the project outcome to be knowledge on how to "attain a meaningful dialogue with the customers about energy flexibility" (Ulk, unpublished working paper, 2011). Although a meaningful dialogue may be relevant to making customers accept DE's control of their heat pumps and of charging of electric vehicles, the focus of the user study did not fit Distribution's perspective very well. The final report on the user study revealed many interesting findings on participants' engagement in moving laundry and dishwashing from day to night and using the intelligent power nodes to survey and control the standby and power consumption of appliances such as TVs and computers. However, when considering Distribution's explicit disinterest in ordinary household appliances whose relatively small electricity consumption was considered irrelevant for any substantial load shedding, the relatively strong emphasis on these findings seems rather odd.[2]

[2] The eFlex project started out as collaboration between DE Sales and Distribution, but the project was later completely separated from DE Sales due to the growing regulatory focus on reducing the advantage of combining trade and distribution within the same company. Sales' interests in developing new services and products may have influenced early design options in relation to the GWR system and the framing of the project—it should "be a commercial stepping stone in the attempt to handle the business models of the future" (Alexandra Instituttet 2010, p. 3).

Learning from eFlex

Despite these viewpoints, DE found the user study useful. On the technical side, for example, they found significant flexibility potential in the heat pumps, and the tests provided ideas on how to improve the set-up—e.g. the optimisation algorithm needed to be developed further, and the heat pump portfolio should be controlled more intelligently. On the behavioural side, the household visits showed both a relatively large willingness to be controlled and also fairly little comfort loss. In general, the user study touched upon many of the questions that DE wanted answered in the seven deliveries, such as segmentation (although without the desired ability for up-scaling), identification of motivations for flexibility and development of communication principles. The study had also confirmed two hypotheses: first, that home automation can promote flexibility, and second, that “electricity is life” and people are not economically rational in any simple sense—price is not the only motivation (antropologerne.com 2012, p. 8). Actually, the project questions the traditional framing of motivation which maintains that economic rationality (like savings) is opposed to moral considerations (doing the right thing). In this case, participants consider the price to be a ‘moral economic signal’ about what to do for the common good.

Most of the findings in the user study confirm insights from existing literature about visualisation and feedback about electricity consumption (e.g. Darby 2006, 2010; Hargreaves et al. 2010), household energy consumption (e.g. Gram-Hanssen 2010, 2011) and family and ICT in everyday life studies (e.g. Røpke et al. 2010). However, since the study was a consultancy job, the main aim was not to engage with this literature but to make insights available for practical use. The project team found it provided useful insights despite not generating all the results they had hoped for. Much more time than anticipated was used to deal with technical problems with the equipment—server break downs, malfunctioning power nodes, etc. However, antropologerne.com argued that the process itself was a result in its own right. The involvement of households thus had an influence internally in DE—what the eFlex project leader called ‘an unexpected side effect, but probably one of the most important ones’. Due to their former monopoly status, electricity companies tend to view households as ‘loads’ rather than people (as the CEO of Danish Energy Association said at the eFlex conference), so the project rehearsed a more market-oriented relation to customers. The study was also a test-bed for new intra-organisational cooperation (also involving the IT department) and enforced a new type of cooperation between the IT company producing the GWR equipment and DE. This is itself a relevant exercise for facing a possible smart-grid future, since the ‘old’ energy sector and the ‘new’ IT sector differ considerably with regard to their relation to their product and customers.

For the engineers in DE, it was useful to consider how the diversity of households’ comfort practices made the technical calculations difficult. One reason for these productive insights and the learning achieved among all stakeholders in the project is related to the co-creation method that antropologerne.com applied through user and analysis workshops with DE and the methodology that emphasised photo and video recordings during household visits. During the project, the varying backgrounds of the participants in the analysis team—consisting of researchers, consultants and engineers working in industry—meant that the actors had very different conceptions of what constitutes knowledge and interesting research questions. The more or less unstructured video recordings of parts of the interviews, e.g. would normally not be the chosen method in a sociological research project. However, the video recordings were not only meant as material for analysis; they were also an important part of the co-construction process—a ‘translation’ tool—and were an essential part of the delivery workshops with DE, where selected video clips were often screened.

Aligning users in networked system innovation

In addition to various kinds of learning, the eFlex project’s benefits also related to branding and political impact. Carrying out such an ambitious project contributes to DE’s positioning as a strategic system builder in current smart grid development. At the eFlex conference, the minister of Climate, Energy and Buildings could not emphasise enough what a great success the eFlex project had been—and that he expects to integrate the results of the eFlex project in the planned Danish smart grid road map. The project can be said to develop a role for households that fits the smart grid system demands. It has explored and constructed a user image that can serve as a valid argument in the political battle to implement a smart grid—a system that integrates users who co-manage their electricity supply in a way that satisfies large centralised energy system actors' demands. According to this image, the users themselves are interested in demand management of their heat pumps, for example, and this message is strategically communicated through e.g. organisation of the eFlex conference with a press release that announced, 'Just move my electricity consumption'. This construction was supported by the nursing of the participants: For example, as an expression of gratitude for inviting the anthropologists into their home, the participants received little gifts from DE and many felt 'pampered' and important from all the attention given them—e.g. when they were invited to events such as the Futures Night and addressed by the then CEO for DE, Anders Eldrup. As many of the participants were lead users, they would probably be positive from the outset towards taking on the expected role, and if they were not, they would have to be rather resistant to not 'buy into the image' through the process.

Based on these observations, we suggest that user-oriented innovation in relation to networked systems calls for the supplementary concept of *the aligned user*. The eFlex project can be seen as a mediation junction (Schot and de la Bruheze 2003) where the projected DE users and the designers of the GWR equipment meet both some real users and the represented users constructed by antropologerne.com, and one outcome of the mediation and negotiation process becomes the aligned user—the user that can serve as an argument in the system-building process.[3] In the design process of large networked provision systems, it is not only relevant to include users in order to develop a market for a specific product or service; since users serve as important co-managers in the functioning of the system, it is also important to construct an image of a user who needs the system that the system builders aim to create. Relating the discussion on the aligned user to the theoretical discussions on lead users referred to in the introduction, we suggest that involvement of lead users—like many of the eFlex pilots happened to be—may serve a tactical purpose. Although the findings may not be generalisable and may not anticipate market needs, they may be useful as arguments.

The road to a low carbon future?

The question then remains whether the system that is being created, and the user roles related to it, actually promotes a low carbon future. Obviously, the thought behind creating a smart grid is that it will enable the integration of large amounts of renewable energy sources and thus contribute to a low carbon future, but the development may also involve counter-trends.

Energy savings and counter-trends

The main intention of the eFlex project was to develop an interest in peak shaving. The GWR system was seen as a means to increase consumers' interest in electricity and to encourage learning about the patterns of electricity use—learning that was expected to lead to increased interest in load shedding. This aim was achieved successfully, and in addition, considerable electricity savings were realised. Some reduced electricity consumption from heat pumps was 'replaced' by other forms of energy (firewood), but this issue was not considered relevant to the project. As in other smart grid projects, it was generally considered important that the results be achieved with little loss of consumer comfort, and it was not meant to challenge household expectations regarding indoor temperature, the 'natural 21–22 °C' (Shove 2003).

In the longer term, home automation may become part of a general trend towards the development of the smart home, where 'boring' demand management is made more attractive by bundling it with other services, which is described as "funwashing" (Nyborg and Røpke 2011). At the eFlex conference, it was evident that many actors consider the smart grid path as a way to develop new business and growth opportunities for the ICT sector and that they emphasise comfort and convenience for the 'users of the system'. Such new services may add to electricity consumption rather than savings. Moreover, the GWR system is designed to change certain practices and reduce

[3] Just for clarification, the idea of the aligned user as a tactical move in relation to a wider strategic process of system building differs from Akrich's (1995) discussion on alignment of user positions. She focuses on the challenges designers face in the design process where different methods are applied to develop and promote user representations in relation to a particular artefact and where a successful design depends on the reconciliation of the results of these methods.

consumption, but as Geels and Smit (2000) write concerning the generative capacity of ICTs, perhaps these technologies may also create new, unforeseen (energy consuming) practices.

Other systems could be constructed

The eFlex project is a strategic move toward actively naturalising a specific future for energy provision—the smart grid path—in the midst of a messy transition with competition between many possible pathways. Although the ‘hydrogen economy’, for instance, may be an unlikely future alternative, other socio-technical configurations for a sustainable energy system could possibly challenge the presented ideas about technologies, ownership structures and practices (Walker and Cass 2007). It may not be self-evident that a centralised structure is the only way forward: localised alternatives may be preferable as suggested by research communities concerned with renewable energy self-sufficiency and the off-the-grid movement. Perhaps, a more active household role as owners and managers of their energy supply in local communities might engage them far more in participating in transforming the energy system towards sustainability (Späth and Rohracher 2010). A few participants in eFlex, in any case, demonstrated their interest in actively engaging in independent development of new solutions.

There may also be reason to discuss the current institutional and infrastructural lock-in related to a transport and heating system based on electrical vehicles and heat pumps, although the two technologies do have wide-ranging potential for ‘greening the grid’. Attention should at least be paid to co-evolution between systems and practices, such as increasing mobility or higher comfort expectations (Strengers 2008). One electrical vehicle owner in the eFlex study, a father of four, explained how he and his older children loved to drive the electric car because it was so easy, comfortable and silent. In addition, because of its convenient small size, it had replaced many of the family’s bicycle tours, e.g. for grocery shopping; or the youngsters would use it when going to soccer training, which the father would never allow with the gasoline car. The low operating costs of running an electric car were not mentioned, but probably contribute to the change of practices. Another study has shown increasing mobility in relation to introduction of electrical vehicles, despite the simultaneous introduction of measures aimed at shifting mobility behaviour, such as promotion of car-sharing or public transport (see, e.g. Hoogma and Schot 2001). Likewise, studies of heat comfort practices in connection to the introduction of heat pumps in Denmark show that heat pumps create new norms for higher indoor temperature in winter (Christensen et al. 2011).

Concluding remarks

The eFlex project has been one of the first smart grid demonstration projects in Denmark where the ‘consumer side’ has played an essential part, and DE is planning to integrate the results in several others of its smart-grid-related projects. The project has been a first step in trying to open up the ‘black box’ of households, which seems to be a core concern for many smart grid actors in Denmark. In the ‘old’ electricity system, these were merely ‘loads’ that were predictable and ‘calculable’, but they have become a new ‘unruly factor’.

In the current struggle to develop a more sustainable energy system, however, we also call attention to the ‘aligned user’ and the political nature of this type of user studies. They construct and naturalise certain futures that fit the agenda of the strategic system builders—for instance, just by verbalising them as ‘the way to go’. Communicating that certain users are willing to accept the solutions can be an important part of the marketing, including the political marketing, of a new and unfamiliar product. In addition to studies such as eFlex, we also recommend more studies of households and their role in sustainable transitions, which challenge to a higher degree current institutions, systems and practices.

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11 Paper III

11.1 Lead users and their families: Innovating flexible practices in the smart grid

Lead users and their families: Innovating flexible practices in the smart grid

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Abstract

Households are increasingly the centre of attention in smart grid experiments, where they are dominantly framed in a role as 'flexible consumers' of electricity. This paper reports from the Danish smart grid demonstration project eFlex, which aimed to investigate the 'flexibility potential' of households, and it shows how householders are far from just 'consumers' in the system. Drawing on empirical material from ethnographic fieldwork in 49 households that tested smart grid equipment, the paper firstly demonstrates how eFlex users were also creative innovators. Secondly, by integrating user innovation literature, domestication theory and practice theory, the paper moreover illustrates how the eFlex equipment interacted with a variety of collectively shared everyday practices in the household and argues that this unique family context accordingly had implications for the 'innovative capacity' of these pioneer users. The paper thus calls for smart grid stakeholders to begin taking the 'innovator role' of smart home users seriously, but equally calls for a more contextual and situated perspective when involving innovative users – their families have an equal part to play in the development of the smart grid.

Key words: user innovation, family context, smart grid

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Introduction

There is no end to the possibilities and benefits embedded in the vision of the smart grid. Globally, it is teeming with projects, plans, experiments and policy road maps for developing this modernisation of the energy system. According to the smart grid stakeholders, one of the important tasks for realising the smart grid is to promote 'flexibility' on the consumption side. Most smart grid projects to date have focused on developing technologies, but increasingly the 'consumer side' has been the centre of attention (Verbong et al., 2013), where the challenge is to unravel how end-users can be 'motivated' to take on the role as flexible consumers.

The bulk of these projects have a rather individualistic and techno-economic approach and often test traditional consumer incentives through quantitative methods by, for example, surveying the response to price signals or detailed information on energy consumption (Gangale et al., 2013).

This paper reports from a smart grid user study which aimed to explore what additional motivations could be in play regarding customers' 'flexibility potential'. The eFlex project was a user oriented innovation project that was commissioned by the largest utility company in Denmark, DONG Energy (DE). The company hired a consultancy firm to generate in-depth qualitative knowledge on the use of smart grid technology in everyday life through anthropological fieldwork in households in the Copenhagen area.

During the analytical work with the empirical material from the user study, an interesting yet largely neglected issue so far in literature on households and the energy system appeared: *users are very active innovators* (although the theme is increasingly gaining attention, see, for example, Heiskanen & Matschoss, 2012; Hielscher et al., 2013; Hyysalo et al., 2013a; Hyysalo et al., 2013b; Ornetzeder & Rohracher, 2006; Smith et al., 2013).

In the eFlex user study it was evident that many of the 'pilot users' were extensive do-it-yourself enthusiasts, who not only found innovative uses of the equipment they were given, which moved beyond its intended use and had ideas for its improvement, but also performed concrete technical innovations to it. That the users' innovative capacity in relation to developing the smart grid has not been explored more is especially peculiar in a Danish context, as there has been an intensified focus on it since the government in 2006 announced it would spend DKK 420 million on a user driven innovation programme, which would last until 2014 (Elgaard Jensen, 2012). A few smart grid projects in Denmark have built on user involvement in the development of energy technologies and systems (e.g. DREAM, eFlex, MCHA), but they have not focused on actual user innovations.

This paper will focus on this particular perspective (see Nyborg & Røpke, 2013 for other aspects of the eFlex project) through the following research questions:

- How is the eFlex equipment integrated into everyday life in households?
- Did the householders make innovations to the equipment and what did the family context mean for the innovative processes?
- Why did the eFlex project and innovations lead to conflicts in the families? Do innovations to networked systems differ from innovations to products?

Although these questions depart from the questions normally posed in smart grid user studies, the answers will be interesting to system builders, as they address issues about 'the sources of innovation' (von Hippel, 1988) and underline how designers of future systems should recognise that "creativity on the fringes should be appreciated and brought in" (Elgaard Jensen, 2013).

Moreover, by approaching the empirical material with a theoretical perspective, which has roots in science and technology studies, I also aim to argue for a more situated, contextual and systemic perspective on user-driven innovation than the one Eric von Hippel and colleagues represent. Accordingly, my analysis of empirical data will build on the integration of three theoretical perspectives, which in combination reveal under-emphasised dynamics concerning innovative processes in the 'residential sector' and allow me to add some insights to the literature on user-driven innovation: domestication theory (Berker et al., 2006; Lie & Sørensen, 1996; Silverstone & Hirsch, 1992), practice theory (mainly as developed by Shove & Pantzar, 2005; Shove et al., 2007) and literature on user innovation (von Hippel, 1988; 2005).

The article will be structured as follows: First the eFlex project and the user study will be introduced, followed by a description of the theoretical frame. The empirical findings are presented afterwards. These concern how the equipment was domesticated and how it interacted with a variety of domestic practices; how the users made various innovations, and how these processes and the affordances of the equipment led to conflicts and negotiations in the families. Finally, the paper will discuss how context matters for innovative processes and why the equipment's networked character and interaction with many domestic practices required many considerations and sometimes led to conflicts.

The eFlex project

In a Danish context, the transition to a low carbon energy system is dominantly framed as an issue of integrating more wind power and using the increasing electricity production for heating (heat pumps) and transport (electric cars) (Energinet.dk & Dansk Energi, 2010). By enabling 'flexible' consumption patterns, the smart grid is argued to resolve issues concerning an increasing share of intermittent energy sources in the system and escalating peak loads from, for example, electric cars and heat pumps.

The eFlex project was commissioned by DE Distribution and conducted throughout 2011. It involved the testing of new smart grid prototype technologies for demand management of electric vehicles, heat pumps and domestic appliances in 119 households in DE's distribution area. The consultancy firm Antropologerne.com was hired to perform a user study that explored the customers' price sensitivity and different motivations for being flexible consumers. The author was allowed to participate in the user study and conduct 11 of the 49 household visits in total included in the user study.

The eFlex project design and intended use[vi]

A basic element in the project design was testing of a home automation energy management system, which supported a new communication interface with DE and enabled visualisation of the customers' appliance-specific consumption. The hypothesis was that it would create a new relationship with DE and with electricity as a product, which would encourage flexibility and increase customer acceptance of supply interruption – as well as providing the ability to automate the management of consumption conveniently.

This system consisted of a number of intelligent power nodes, which the users could control via an on-line 'portal' that could be accessed from either a computer or from an iPod Touch. If the users connected the power nodes to appliances around the house, they would be able to see on the portal how much power each appliance consumed throughout the day. They could turn them off from the portal, or they could program certain power nodes to turn off or on collectively at specific times of the day, and thus make, for example, an 'out' profile, or

[vi] In this paper I will use the phrase 'intended use' and not the stronger concept of a 'script' (Akrich, 1992), which I have not explored in detail in relation to the eFlex equipment and which in any case seem unfit to use – as other interactive ICT's the equipment appeared to "have more complex affordances than clear scripts" (Hyysalo, 2010: 245).

‘sleep’ profile’. Moreover, the participants agreed to transfer to hourly pricing and were also offered variable distribution grid tariffs. Accordingly, the next 24 hours’ dynamic prices, which were visible on the portal, and which the customers were priced after, were based on a combination of dynamic spot prices and variable tariffs and could differ from 1.50 kr. (0,20 €) pr. kWh to 4.30 kr. (0,58€) pr. kWh. Hence, the users could utilise this information to construct certain profiles or turn devices on/off individually at certain times in periods when the price was low/high.

The eFlex project design included 81 households with a heat pump (HP), 9 households with an electric car (EC), and a ‘control group’ of 26 ‘ordinary’ households (OH) without either. All three groups had the energy management system described above. In the heat pump group, DE could reduce consumption – or ‘optimise’ – the heat pump externally for periods of one to three hours through a ‘relay box’. This group had an extra feature on the portal they could use to follow DE’s interaction with the heat pump. Likewise, the charging of the electric car batteries was controlled externally by DE. In this case, the users had to specify through the portal at what time in the morning the battery should be ready and charged, and its minimum percentage level (see Nyborg & Røpke, 2013 for a more detailed description of the design, method and results of the eFlex user study).

The empirical material used in this paper consists of field notes, photos and videos from the 49 household visits, as well as dictaphone recordings from the author’s own 11 visits. Each household visit lasted approximately 4-5 hours and included lunch or dinner with the families as well as a ‘grand tour’ of the dwelling. After each household visit elaborate field notes were written on PODIO, a social media platform that functioned both as a project management tool for DE and antropologerne.com and as a platform for the householders to communicate with each other and the eFlex project team.

The analytical process resembled the ‘immersion/crystallization’ style (Borkan, 1999) by relying on intuition and prolonged ‘immersion’ in the data. The analysis began by listening through all the dictaphone recordings – often 1-3 hours from each household – and writing down immediate ideas and notes for emerging themes. Subsequently, 5 of the 11 dictaphone recordings were transcribed verbatim by the author as these focused particularly on heat pumps and were to be shared with other researchers for another paper. Concomitantly with this process, all 49 household field diaries were read through several times and emerging themes were further developed and the family stories were written. The dictaphone recordings that had not been transcribed were listened through again and relevant parts in these were also transcribed. Video recordings and photos were mostly used as ‘back – up’ for field diaries and dictaphone recordings; In a few cases it was for example unclear what was meant in a field diary written by another fieldworker or what was being said on the author’s own recordings and looking through relevant photos or video-material could clarify these issues.

Theoretical frame

As stated in the introduction, the theoretical frame applied in this paper builds mainly upon ideas taken from domestication theory, practice theories and user innovation literature. Whereas domestication theory is an obvious candidate when analysing what happens to both the artefact and the family when new technology enters the front door, practice theory clarifies how the technology comes in clinch with a variety of everyday practices. This aspect is not very elaborately dealt with in domestication theory. Here focus is more narrowly on practices ‘with’ an artefact and how artefacts *develop* in the continuous interaction with a household’s unique culture and identity – its ‘moral economy’ (Silverstone & Hirsch, 1992) – which in fact makes a domestication analysis “similar to studying acts of design and innovation” (Lie & Sørensen, 1996: 8). The notion of ‘domestication’ refers to how a new and unfamiliar technology has to be ‘housetrained’ when it enters a household. The theory emphasises the context-dependent appropriation of artefacts and how their role in a family is an outcome of negotiations. Moreover, these “everyday struggles… may have important effects on the shaping of technologies and its ‘consequences’” (Lie & Sørensen, 1996: 11). Domestication is a two-way process where artefacts are incorporated into routines and value systems of everyday life and may be ascribed new meanings and functions, but they may also assist in breaking habits or developing new routines in a family. Moreover, by drawing on ideas from practice theory, the emphasis is put on how new technology both changes some practices of the household (according to DE’s intentions), but conversely, the eFlex technologies are also integrated in some practices and made to function in these practices. Domestication is thus the way each household finds its own unique way of integrating the equipment as an element in the performance of a range of its everyday practices, which accordingly may develop and diversify the practices (Røpke et al., 2010) or lead to the creation of entirely new ones. In this paper, the artefacts considered in the domestication processes are the portal, iPod touch, power nodes, ‘information’ (variable prices, tariffs etc.), PODIO, heat pump and electric car. ’Equipment’ usually means the portal, iPod and power nodes.

By drawing on practice theory, the emphasis is on how ‘a practice’ is more than ‘user practices’ with an artefact. Instead, practice theory has social practices such as 'cooking', 'playing soccer', 'shopping' or 'googling' as the ontological units of analysis. Thus, a practice can be seen as a cluster of activity, which can be conceived of as an entity and which is endurable and recognisable through space and time (Shove et al., 2007). To take an example, the practice of cooking dinner precedes the individual cook, who momentarily and at a specific place performs the practice by linking several elements such as artefacts, bodily movements, meanings and know-how – i.e. they ‘use’ a stove, know-how about how to chop a carrot and meanings such as caring for your children or norms about health. Individuals thus “face practices-as-entities, as these are formed historically as a collective achievement; and through their own practices-as-performance, individuals reproduce and transform the entities over time. Individuals thus act as ‘carriers’ of practices” (Røpke, 2009: 2491). Consumption studies have in recent years also drawn upon a practice theory perspective, by pointing to how resources – energy and materials – are appropriated and consumed “in the course of engaging in particular practices” (Warde, 2005: 131). Thus, focusing on the material component and its role in the performance and reproduction of practices has also inspired work in innovation and technology studies by emphasising how technological systems or products always co-develop with changes in practices, and how new technological systems such as smart grids both meet and make demands and needs (Shove, 2003; 2012). Finally, practice theory is also well equipped to investigate “the complex temporal organisation of everyday life” (Shove et al., 2009: 1). In a practice theory perspective an individual follows a path in time and space, and each individual carries out practices that take up time and have to take place in space. This also implies coupling constraints, as Røpke argues: “As practices often involve other people, other living organisms as well as man-made and material objects, they depend on the coupling and uncoupling of the paths of all these human and non-human “partners”’ (2009: 2493). Thus, coordinating practices and paths in a family is hard enough even without new demands that certain practices are dislocated in time through ‘flexible consumption’.

Finally, literature on user innovators extends domestication theory by turning our attention to the actual amendments that users are able and motivated to perform on artefacts. However, compared to the other literatures just presented, Eric von Hippel's notion of 'lead users' (von Hippel, 1986) presents a more individualistic and teleological conception of user innovation, with no attention paid to how the meaning and use of artefacts are dependent on the context they are situated in, which thus matters for what innovations are possible or make sense.

Lead users are characterised as being the very first to take up a new product, and they are likely to be the most innovative of users. The stronger 'lead user characteristics' a user possesses, the more commercially interesting his innovations tend to be (von Hippel, 2009: 30). Although research interests in this literature are broad and several explanations as to why users innovate have been presented, focus is often on the 'economic incentives operating on users', i.e. *'the expected benefit'* of innovating and '*low innovation related costs'* (Bogers et al., 2010). Lead users benefit from solving needs early because they expect 'high rents' from using a solution to their very specific needs – needs that are ahead of the marketplace and will become general only months or years in the future. Moreover, they have the advantage of having cheap access to 'sticky information': Much user-need and use-context information is very 'sticky' – it is tacit and costly for producers to obtain from users (von Hippel, 2009). Von Hippel argues that consumers are a major source of product innovations (2011) and proposes that companies can tap into the innovativeness of lead users through the four-step 'lead user method' (Urban & von Hippel, 1988): In step one, emerging trends and market needs for a product area are identified; in step 2, a lead user group who is 'at the leading edge of the trend being studied' is identified; in step 3, lead users are interviewed to gain insights about emerging needs and to provide input to concept development. In step 4, the new concept is tested among 'ordinary' users. Later, the concept of 'user toolkits for innovation' was introduced (von Hippel, 2001). Through this method, manufacturers supply users with specific tools that support them in developing and testing new products via iterative trial-and-error. Von Hippel's work has been very influential and over the last 10 years the interest in 'user-driven innovation' – characterised as the active involvement of users in the design and production of a new product or service – has grown tremendously in Denmark, since this approach adds extra value to products that can't compete on price or technology compared to other countries (Rosted, 2003).

Results

Empirical data

The findings presented in the following consists firstly of two detailed family stories and secondly, I draw on these two stories supplied with empirical material from the rest of the household visits to elaborate more specifically on cross-cutting themes in the material that are related to my research questions.

The family stories are included to exemplify and give a sense of how the eFlex project became situated in different and unique family contexts; because they are *family* stories they illustrate how the lead users were enmeshed in a household's moral economy and the web of interconnected practices that comprise it, which mattered greatly for the innovative processes and their outcome. Moreover, the stories exemplify three themes, which I, as said, will explicate more on afterwards: The story of Peter & Charlotte is a story about *domestication*, whereas the story about the lead user Benny & his wife Marie illustrates dynamics concerning *innovative processes in a domestic setting*. Both stories also illustrate the *negotiations and conflicts* that follow in the wake of introducing such equipment in a (innovative) household.

Family story of Peter & Charlotte

Peter and Charlotte love living in their large 'country house' close to the forest and with a panoramic view over the 2.5 hectares of land they own. As Peter says, 'I am a man of nature'. The house resides in a 'well-to-do' part of northern Zealand, and the married couple share the house with their two teenage sons and their yellow labrador Zapp. Peter runs a clothing shop, but is very active with outdoor activities and with renovating the house, and he would really like the boys to enjoy nature just as much as he does. He thinks they spend far too much time playing on the computer.

The eFlex participation is mainly Peter's project. Although less enthusiastic, Charlotte is curious about what it actually is in their household that consumes most electricity. 'Is it turning on the clock radio, the oven or the lights outside?' she asks. However, she finds it difficult to become part of the project, and she and the two boys have already gotten annoyed with how Peter is running around with the iPod all the time. Peter is still experimenting with where to put the power nodes and so far none have been placed in the dining room as Charlotte finds them too ugly and not fitting in with the interior decoration. Peter has put power nodes on the TV in their bedroom, on their B&O clock radio, in the guest room for Charlotte's laptop, on their video surveillance cameras outside, on the TV, lamp and computer in each of the boy's rooms, on their routers and on the quooker and washing machine in the kitchen. The quooker is a tap in the kitchen, from which you can pour boiling water directly into your cup. The couple has realised that the quooker uses a lot of electricity because it is always on 'stand-by' – actually it uses around 1400 Watt for a few minutes several times a day, Peter can see on the portal. So now he has made a profile that turns it off at night where they never use it. He can see that the biggest consumers in the home right now are the boy's rooms and the kitchen.

Peter always goes to bed around 12 at night – unless he stays up a bit to do some programming to improve the webshop of his store. He has set up the system so that the TV in their bedroom is the 'master', i.e. when he goes to sleep he turns off the TV, and all the rest of the things in the house connected to power nodes are also automatically turned off. Peter thinks the system functions very well, although he must admit it requires some skills to learn how to use it and its logics. One morning they were all late, because the clock radio did not come on because it was set on a wrong profile – and Charlotte could not get her cup of tea because the quooker had not been on when they woke up.

Peter's system of turning off all devices through his iPod when he goes to sleep also means that he turns off the boys' light, TV and computer. Otherwise they will continue playing all night, get up late and be too tired in school. "So I also use it a little to control behaviour now that I have the possibility, right?" as he says. "I'm trying to raise them to know that a good night's sleep is important". He thinks they shouldn't disturb their friends after bedtime. Actually he did signal this to them even before he had the eFlex system by shutting down their IP addresses on the internet. However, Peter recognises that often the boys would instead just use the neighbours' open WiFi, so it's more for the signalling effect, he says. The couple realised that the boys' ICT habits actually count for a great part of the household electricity consumption. After they started staying in their rooms at night playing computers, watching TV or communicating with friends, their electricity bill rose by 3-4,000 kr. (400–530 €) a year and now the eFlex project has really confirmed that it is connected to their 'staying-in-the-room-at-night' habits, Charlotte says. Peter estimates he only saves around

500 kr. (70 €) a year turning off things at night, but he likes the idea that all unnecessary standby consumption is turned off. Peter also likes using the iPod and portal as a way of getting a feeling of what is going on at home when he is at work: "I think it's fun to open it [the portal] from the store and see if it's all running… and see if the boys have come home… then I can see if the computers are on". Actually, the eFlex equipment has somewhat become part of Peter's incidental 'surveillance' of the boys and their dog-walking chores. The adults take turns walking Zapp in the morning, as do the boys when they come home from school – the agreement is to take him for half an hour in the woods. However, after the family got the surveillance video camera outside, Peter and Charlotte accidentally noticed when looking through the pictures how the boys 'cheated' and just opened the door to let him out for 5 minutes. And now, even while at work, Peter can also 'survey' whether they are actually in their rooms and playing on the computer instead of walking the dog. He can see "what time he turns on the computer, right? I can see if there is no electricity consumption. I can look back on the entire past week and see when they've been on and when they've not been on. They don't know quite how much it's actually possible to see on it, you know?"

Peter has had discussions with Charlotte about how they can be flexible, and he wants the washing machine and dishwasher to run at night, but Charlotte thinks that the clothes get wrinkly from lying in the machine all night. Furthermore, although she wants to 'learn how to save energy' and 'do things smarter', as she says, things get too much of a hassle and an inconvenience if the machines can only run at night: "If I'm suddenly cooking and I have a lot of pots and pans, then surely the machine just needs to run, so I can also use them later in the evening. Nor can I just plan to always wash clothes at night, because I do not have the time to hang them up".

Family story of Benny and Marie

Benny and Marie are a couple in their sixties who have both retired early. Benny, however, still works 10-15 hours a month as an IT consultant for his old workplace where he was employed as a mechanical engineer. They have lived in the same detached house in the suburb for almost 40 years.

Benny and Marie have had a ground source heat pump with a 300 L buffer tank for three months, and they were both shocked at how big a mess the garden was after they had put the tubes in the ground. They bought the buffer tank because Benny wanted to take advantage of the cheap electricity their electricity company 'Modstrøm' offered them at night by storing extra heat in the tank. But then Benny found out about the eFlex project through a newsletter, which also offered cheaper prices at certain times of the day. They had been Modstrøm customers since 2008 and only recently changed to DONG Energy, because they had to as part of the eFlex project. Marie adds that they were accordingly already 'tuned in' to time-shifting their dishwasher and washing machine to night-time. Benny is very preoccupied with the heat pump and is very willing and proud to show how he can follow its 'workings' on the eFlex portal. He has even volunteered for another project called 'control your heat pump' and explains "you get more measuring equipment on your heat pump… you get to see even more how well it works, you can measure your COP value and so on…". Benny considers DE's optimisations of the heat pump too weak, among other things because he has the buffer tank. Consequently he shuts off the heat pump completely between 8-12 and 17-19, where the tariffs are the most expensive. However, he has found a way to 'cheat' the heat pump in order to get heat in the radiators anyway during these expensive hours: Between 5 and 7 in the morning where electricity conversely is cheap he sets the heat pump to deliver a living room temperature of 27 degrees so the pump heats up water to meet that temperature. However, his thermostats on the radiators in the living room are not 'fully open', as many heat pump owners are told they should be, but are instead put on, for example, 21 degrees – this means the extra hot water is saved in the buffer tank instead and can be used in the expensive hours between 8 and 12.

The couple do not have a fireplace, which many other eFlex participants say they light up if they think DE's optimisations lower the household temperature, but their walls can also store a lot of heat, he thinks. Marie tells me she never turns up the thermostats as she doesn't believe it matters. But she is happy the heat pump can be set to a 'travel mode' during the winter, so the temperature does not go below 10 degrees and "the living room plants do not suffer any hardship". Marie is not always satisfied with Benny's experimentation with the heating. She doesn't know, for example, how to turn up the heat in her hobby room on the 1st floor. She tries to turn up the thermostat "but I really don't quite know what is going on in this house. But, I try to turn it up… Benny, he tries so many things, so what's going on all the time, I'm not quite aware of", she says. Neither is she totally happy about the temperature of the water after they have got the heat pump: "It's got better, because it's been set a little low, but I still think it's bad with the water for dishwashing, because it has to run for so long for it to become warm enough for grease and so on to come off, and I don't think he has quite finished regulating that yet". Benny emphasises that he *has* finished regulating it and that the temperature can't get higher than 50 degrees, unless the HP needs to use too much electricity. He has, however, set the HP to heat up the water in the system above 60 degrees about once a month to avoid legionella bacteria contamination of the water. He doesn't believe the optimisations have any influence since they never eat before 19 or shower between 8 and 12 or from 17 to 19. But Marie says "there are things such as when I for example bake a cake and cookie dough and so on. I use water in the kitchen at many times during the day… it's not quite warm enough".

Benny has experimented a great deal with putting power nodes on the refrigerator, freezer (the nodes are locked so it's not possible to accidently turn them off) and dishwasher, and he is happy he can now see how much electricity they consume. He tried to put a node on the washing machine and dehumidifier in the basement but it kept shutting down. He also has a node on the circulation pump for the HP, which he at first made a turn-off profile for during the night, but now he lets it run because the price is low at night anyway, so they may as well have that comfort. Moreover, he put a node on an outside lamp, on their music system, DVD, TV, laptop, and the radio in the living room. He noticed that their hard disk recorder uses a lot of electricity, but he couldn't turn it off to save stand-by because it's an old model that forgets all the time settings when it's turned off. Marie's frustrations not only concern the heat pump but also the eFlex equipment, because she does not really understand what the iPod or power nodes are for. Benny already has two iPods on which he recently downloaded the eFlex app and all their music, so they can bring them on car vacations, for example. He secured the iPod from DE onto a little loudspeaker system in the basement besides Marie's laptop, computer screen and printer so she can turn her ICT devices on, but she's not happy about it:

"It's really hard, because at the same time all our music is set on completely different methods… You know, Benny loves these kinds of things… 'then you just have to push there and there' you know… and then constantly new and new and new things come along and I'm just not that much into machines… there are too many thingies and gizmos, and they are not just DONG Energy's".

Domestication and de-configurations

As we can observe in the family stories, the use of the e-Flex equipment and the meanings ascribed to it are quite different between the two families. The equipment became domesticated into a family setting with its own unique moral economy, which was under constant negotiation, and which had an influence on what the equipment was actually used for and what practices it co-developed with. Taking Peter's story as an example of a domestication process, we saw how the equipment supported his and Charlotte's interests in identifying the devices consuming most in the household, quite in line with a household moral of avoiding unnecessary waste. Moreover, it inspired reflections on washing clothes and kitchenware at night, which was in line with the intended use of the equipment. However, the project and the eFlex equipment also *became something else* through the domestication process – e.g. a means for Peter to control his sons. The project entered a household with a moral economy connected to ideas and meanings about 'an active lifestyle' and a love for 'nature'. Moreover, Peter considered it valuable for his boys to get enough sleep to perform as well as possible in school. Peter's use of the eFlex equipment was clearly domesticated into this setting, since he used the eFlex equipment in his already existing practice of controlling and surveying the sons through the video camera or the shutting down of IP addresses to signal 'bedtime'. Now, with the eFlex equipment, he instead simply shut down the computers or looked on his iPod from work when they had been in their rooms and what they were doing there. This domesticated use of the eFlex technologies was both for 'getting a feel of home', but also to explore and confront the boys' 'passive' computer games – especially at night – or their cheating with walking the dog in the forest, which was part of the nature he would like them to appreciate more.

Intended and unintended uses

Generally, domestication of the equipment led to both intended and non-intended uses. Concerning the former, knowledge about electricity prices and tariffs on the eFlex portal often inspired the moving of laundry and dishwashing – or even things such as baking and pottery hobbies – to night-time or weekends. The power nodes were often connected to lamps, TV/music-sets as well as computers and were used for identifying 'large consumers' or gaining a better sense of the consumption patterns of the household, which meant for example that they could turn off unnecessary consumption or even replace inexpedient devices. Some users also experimented with using power nodes for 'flexibility', which actually required a rather creative use of the equipment[vii]. For example, the pilot user Hans would make a profile to turn his chest freezer off from 10 pm and until 2 am. In the meantime the temperature had risen about 1 °C, so when turned on again, the freezer would restore the temperature and 'move' some of its consumption to the cheapest period after 2 am. However, as Peter's story illustrated, the equipment was also used in ways that were not according to the intended use. Another example was Martin, a dedicated father and husband, who used the iPod or computer to turn off his 3-year-old daughter's cartoons from the kitchen. *"Then, when it's time for bed, she can see we don't have the remote, because she has it, but then we can say…'now there is no more TV [aired] today'"* – an explanation she would instantly accept. In other cases, if Martin was at work and worried because he couldn't get in contact with his wife through the phone, he could see on the portal she was home, because the TV was on – and he would turn the TV on and off to see if she was awake and 'provoked' to ring him back.

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vii Many users were confused about what the primary aim and intended use of the power nodes was. Whereas DONG Energy had mainly included them to support increasing 'electricity awareness', many of the householders had gotten the impression they were mainly supposed to use them for flexible consumption. This was a type of use, which the design of the equipment did not support very well and accordingly it required quite a lot of inventiveness to find ways to actually use them for flexibility (see Nyborg & Røpke, 2013 for more on this).

Thus, the eFlex project interacted with a myriad of practices as varied as cooking, laundry, dinner and dishwashing, airing-out, watching TV, playing computer, communicating with friends, brewing tea and coffee, commuting to work, lighting a fire in the fireplace, bed-time rituals, 'leisure/passing time' practices, 'parenting', 'walking the dog', theft protection, heat comfort, hobbies and many more. New practices were, however, also created, more in line with the equipment's pre-configuration, e.g. several pilot users took up the novel practice of routinely checking the portal at night before going to bed. Although difficult to state when the equipment was integrated as a new element in an already established practice – e.g. turning on the computer and checking emails before bed – or whether the practice could be 'classified' as 'new', it is evident that something happened to *both* the equipment and to the practices performed in the households. Next, I want to focus more on two specific issues that appeared in the domestication process: user innovations and conflicts and negotiations in the family.

Innovations

Many of the eFlex users were most likely different from the bulk of the population and in a 'Diffusion of Innovations' perspective (Rogers, 1962) they could probably be characterised as 'innovators' or 'early adopters'. In a survey that antropologerne.com made among the 119 households (89 answered), 24% of the pilot users identified them selves as the user profile 'the technical'. This was one out of five user profiles that had been made on the basis of the anthropological fieldwork and the users were asked to place themselves in the category they believed described them best. The other four profiles were 'the economical', 'the curious', 'the participating' and 'the comfortable'. 'The technical' were all male and often engineers or had another technical background. They where among other things described as being interested "in mechanics and/or new technologies, are often frontrunners and are willing to try out new things" (antropologerne.com, 2012: 50). They were more technological savvy than most and had extensive knowledge of the energy system. Several of them already had some sort of 'smart home' systems in the house, such as IHC lighting control or they were prosumers by having installed solar panels or had a share in a locally-owned windmill. They often took a keen interest in the functioning of these technologies – or planned to install them themselves, such as the user Flemming who had bought two m2 of solar panels, which he wanted to solder together and install on his roof. As heat pumps and electric cars are still not widespread in Denmark, the eFlex users were clearly early adopters of these technologies. Moreover, they showed lead-user characteristics for example by innovating on and improving these technologies and making them fit into their particular needs. Often the users were engaged in D-I-Y projects and innovated on a range of products and systems in the home. The user Jens, for example, made an intelligent heating and electricity system in his house, but also found it inconvenient that the house's in-built vacuum cleaner system did not have an on/off button on the handle of the hose, so he made such a switch by using the remote control for a car alarm.

Innovative uses and short circuits

The rationale behind the eFlex project was that the flexibility concerning heat pumps should be taken care of by DE – ideally in such a manner that the households would experience no comfort loss or any sort of hassle connected to providing the flexibility. However, many pilot users clearly expressed a desire to take a more active part in the system, as we saw with Benny and several other users such as Hans, who would turn his heat pump off between 10 pm to 2 am and take advantage of the kickback effect, similar to his freezer experiment. Some users even made actual short circuits to the eFlex relay box. For most of the heat pump types, DE had two ways of optimising through the relay box: either allowing the air temperature in the house to drop, but maintaining production of hot water, or stopping the heat pump completely – and there was a relay for each function in the box. The user Henry, however, thought the first option would not provide him enough savings, so he short-circuited one of the two relays, so the heat pump would always shut off completely during optimisations. As he explained: *"You just unscrew the lid of the relay box and put a cord between the two legs of the resistor… it has been discussed on PODIO and I can see that several others have short-circuited the resistor just as I have"*. Similarly, Jens made an electric hob that allowed him to optimise twice a day.

Fig. 1 Left: Jens observed that DE often only optimised his heat pump once a day, so he made an electric hob that allowed him to optimise twice a day. Right: Martin's home made ground connection for power nodes

Another example was Martin: Power nodes did not have ground connections at the beginning of the project, so the users were not able to safely connect refrigerators etc.: *"So I made an extension cord that coupled the ground connection around the unit itself, and then I posted it on the net and said, well, here I have a solution"*. This self-made solution, however, was not allowed, and DE introduced instead power nodes with earth connections. Often the pilot users also had many more ideas for the improvement of the equipment, e.g. that the power nodes should also turn off automatically when the HP was turned off.

Parallel domestication

The domestication of the eFlex equipment often proceeded in a context of *parallel domestication* processes**.** Besides being a tool for *optimising* the operation of their heat pumps and electric cars, the eFlex equipment was also used as a way of '*getting to know*' and understand them better: Often the heat pumps and electric cars were themselves involved in a simultaneous domestication process, such as Benny's enthusiasm for knowing all about his heat pump and its COP-values exemplified. Similarly, Martin also really wanted to learn more about the charging patterns of his electric car – and the eFlex equipment would help him domesticate his car even further. What interested him about the eFlex equipment was *"…also this thing about surveying a product, does it behave unusually? …Sometimes the charging of my electric car looks different than it usually does, but that also has something to do with temperature and so on. What may be the reason for this?"*

Users 'tap into' companies

In lead user literature, the user is seen as a source of information for firms, who can tap into their innovativeness to produce breakthrough products. However, in the eFlex project the opposite process also became evident, as several users had entered the project to learn more about smart grid development and 'harvest' the knowledge and network that was created and facilitated by DE. The eFlex user Flemming had, for example, bought his electric car to get some experience with the car and had a business plan to develop intelligent charging solutions for the smart grid. He had volunteered for the eFlex project among other to learn and *"to meet someone at get some experiences with it [flexible charging etc]. That, for sure"*. This observation is in line with more recent work on consumer-innovators by von Hippel and his colleagues, who have explored other types of motivations for innovating than gaining benefits from *using* the innovations (See e.g. Raasch & von Hippel, 2013). Consumer-innovators also innovate because they expect profit from *selling* an innovation and both these types of expected benefits – using and selling the innovation – are what Raasch and von Hippel call 'output related motivations'. However, users also expect benefits from the actual *process* of innovating and such 'innovation-process-related-motivations' include, for example, the enjoyment of and learning from participating in the innovation development process.

Innovation in a family setting: Conflicts and barriers

In the following I will present my findings concerning some of the conflicts and barriers I observed in the families relating to participation in the eFlex project. Of course, in some families there were no actual conflicts and in those families where there were, the picture was varied and the reasons for conflicts were many faceted. However, three themes that seemed interesting will be presented here.

Loss of control & equipment designed for one person

The affordances of the equipment did not support a collective domestication and shared use in the family (see also antropologerne.com, 2012 on this), *but* at the same time, the equipment was tied up to the electricity system, which the entire family was dependent on. Often it was only one person in the home that was *'running around with this iPod'* and had free access to the portal 'control room', which meant a loss of control for the other family members. As one wife, Christina, expressed her frustrations: *"Now you have this DONG gizmo, so now nothing is on anymore, so when I get up in the morning and need to turn on the lights in the children's room, that damn device, it has meant I cannot turn on anything…"*. This naturally limited the sort of experimentation that was possible for the pilot users, as Flemming acknowledged:

…But it's also… I really don't dare do so much. Because whenever I do something, it turns off the DVD or the TV and then they all go crazy! So, it's kind of limited how much one dares to do.

Visualisation and surveillance

This sort of 'dominance' that the pilot users exerted could also be related to the visualisation and surveillance of electricity consumption, which the equipment allowed. The eFlex users could gain some insights the other family members could not to the same degree. This meant first of all that already ongoing negotiations about what was in the first instance meaningful to use energy on were sparked into life. Many spouses had different ideas about whether lighting in the garden or in unoccupied rooms was important, or about what the comfort temperature should be in the house. Secondly, the visualisation feature also allowed the surveying of what other family members were doing at certain times and places, which had obvious implications for the power relations in the family. As one wife said jokingly when her husband showed her the portal, *"so that means I can actually go in there [portal] and see, if you are* *doing anything…?"* Not surprisingly, many of the children in the families refused to have any power nodes in their rooms[viii].

Interruption of practices and structural barriers

Remembering that energy consumption happens in the course of performing 'time-and-place bounded' practices, which are often tightly coordinated in everyday life, experimentation with *flexibility* also resulted in conflicts, because other family members' practices were disrupted. In Benny's story, we saw for example how flexibility with the heat pump interfered with Marie's washing-up practices in the kitchen. And as we saw in Peter's story, Charlotte was critical of the idea of postponing the dishwasher or laundry to night-time, because this manoeuvre would mess up her planning. She did not have time to hang up the clothes in the morning, which was a time slot that was filled with other practices that took up her time. This was a problem mentioned by many of the eFlex users' wives. Another example was Hans's wife Liv, who thought that his experimentation interrupted their son's sleeping:

Hans: *But in reality we haven't done much to investigate if it is a problem; there are doors in between and if we close the door, then…*

Liv: *Really, Hans, if he says he can't sleep because the washing machine is centrifuging, then surely I believe him… I don't have to investigate anything!*

Hans: *No, but what I mean is that we have not really done anything to find out if there is a problem and if we could find a solution…*

Such considerations for the life paths of others, which hindered innovative activities, did not have to be conflictual, as in Martin's case. He stopped experimenting with making profiles for the refrigerator to turn off during the day when his wife went on maternity leave and would suddenly stay home all day.

Experimenting with flexibility also clashed with structures outside the home. Martin mentioned how his ability to be flexible with charging his car also depended on his working hours and congestion patterns; with his type of battery, if he were to take full advantage of the cheapest electricity prices in the early morning hours, he would have to postpone the time he left in the morning. Conversely, that meant he would run into another problem of travelling peaks and congestion. The user René similarly expressed how flexibility with laundry not only depended on their 'willingness' to do it, but also on the temporal patterns of their sons' leisure activities: *"When you're a family with children, then you have to do the laundry… the kids have to play soccer tomorrow, their clothes need to be dry"*.

Discussion

Lead users and their families

As the previous sections have demonstrated, when considering user's innovative outputs in relation to smart home energy management technology, there were a lot more dynamics at play than 'a product', 'expected benefits' and an individual with the right 'lead user

[viii] Such "digital panopticon" effects are known from elsewhere as an almost inevitable part of automation (see e.g. Grimpe et al., 2014, Hyysalo, 2007)

characteristics'. The findings illustrate that if we are to better understand the dynamics related to the innovative user, we have to take the specific context in which innovation occurs into consideration. As I have shown, householders adopted and adapted the eFlex equipment "to their local conditions and the particularities of their houses and everyday practices" (Hyysalo et al., 2013b: 491). In other words: the lead users did not innovate in isolation, they were part of a system; the moral economy and practices of the families as well as the material 'particularities' of the house – e.g. size, insulation degree, number of rooms, build-in appliances or accessible power plugs, piping, types of radiators or floor heating, buffer tanks – also had agency (Latour, 1992) and had 'a hand in the innovations' simply because they were all constitutive in defining uses and assigning meaning to the eFlex project. They had an influence on the practices the equipment interacted with, and thus on the types of innovation that were meaningful or even possible at all.

This point is addressed to the user innovation literature, which could be enriched with insights regarding how products are always part of networks and social practices, but it also has obvious empirical implications if smart grid stakeholders will eventually take the innovative capacity of users into account. As Hyysalo (2009) is arguing, other approaches are needed to complement the otherwise dominant focus on the economic rationale behind user-innovation behaviour. Notions such as 'expected benefit', 'lead user characteristics', 'high rents', 'innovation-related costs' and 'the economic incentives operating on users' need to be accompanied by other questions and other insights in relation to why (and where) users innovate and what other factors than the 'innovative mind' – or the collaboration between these in horizontal innovation networks – are at play for the result. The 'system', in this case the moral economy of the household wherein product innovation happens, has important implications for what innovations will take place and how 'commercially attractive' they will be; what will be the benefits and disbenefits of the innovation for the directly implicated people such as the family members. While the lead user methodology and 'toolkits for innovation' recognises the benefits of a 'trial-and-error' innovation process in the user's own environment, the discussion remains one of how these tool kits can enable cheaper and faster innovation processes. There is almost no attention as to *how or why* the use context has a bearing on the innovations. The last 30 years of STS research have pointed to how innovation is part of a network, and that doesn't change because the innovator is a user – the sticky information does not just reside in his head but in the system of which the innovation is part. A user will perhaps be able to point to new product ideas and solutions based on the needs he has already encountered in his context, but, again, needs are not static and innovation happens as a result of a situated interaction (Suchman, 1987). Products are continuously negotiated and integrated in many practices that are shared and developed by the practitioners – in our case the family – and it will be difficult to know beforehand what kinds of use of the artifacts are relevant, and what meaning and function the product will have. It would definitely make sense to call Peter and Benny lead users of smart home energy management equipment and invite them to a workshop, so that they could share their ideas and experiences from having engaged with such technology. However, do they really bring the 'sticky information' from the family with them? The products they help in developing, will they have included all the complexities and different meanings and practices of a family and its specific material setting? Some of it, yes, but a more contextual and 'systemic perspective' on sticky information would perhaps be beneficial. Moreover, it would be interesting to pose more questions about sticky information that are not just about how costly it is to transfer, but about 'what it is' and does 'a' lead user have 'free' access to it? In relation to theories about innovative users: Are the dynamics concerning why, how, where and what 'drives' certain innovations answered by focusing on 'economic incentives operating on users'? A more in-depth engagement with "practices and community dynamics of users" is also what Hyysalo (2009: 254) is calling for in an article on micro-innovations in sports industry development. He emphasises the importance of looking at how the collective user community takes part in reproducing but also changing 'kayaking' practices for which the 'lead users' make innovations. In his words:

"Lead users are like citizens of the ancient polis of Athens: a competent, willing and visible elite who are easily seen to constitute the relevant sphere of action. But analogous to Athen's democracy, without the means to pay sufficient attention to the majority of its inhabitants – peasants, women, slaves and foreign merchants – our view of user innovation would miss important issues if the, less grandiose, inventive inputs of other-than-lead-users were neglected" (254).

When dealing with the innovative user, we should therefore also deal with his or her 'fellow' carriers and the continuous development of the practice the innovation is part of – all carriers of practices are in a sense innovators as well as producers and consumers at the same time (Pantzar & Shove, 2010; Shove & Pantzar, 2005). In the case of innovations to a 'product' such as a 'smart home energy management system' it would definitely make sense to consider the context of the 'household' or family of the innovator, because they also use and depend on the system which is subject to innovations. User innovation research has only explored user innovations that occur in the context of everyday family life by survey (von Hippel et al., 2012) and hence has not addressed how the specific socio-material configuration of each household and the network of meanings, materials and practices the innovator is situated in matters for the innovative processes 'on the fringes'. In short, no attention has been focused on innovations *in* systems, i.e. in more complex webs of artefacts and meanings than just a user-product relation. Neither has there been paid attention to innovations *to* networked systems such as the energy infrastructure. A discussion of the latter and its deep entwinement with domestic practices comes next.

Electricity system element in many domestic practices

The many conflicts and considerations that have been described in the findings related to the large number of domestic practices that were in play, which conferred special challenges for 'the eFlex innovators'. More specifically, the many practices presented a challenging context for innovation for two reasons: firstly, because they were 'hung up' on a 'networked' electricity system and, secondly, the everyday lives of families are already challenged by 'coupling constraints' between life paths and practices, which the eFlex users' demands for experimentation with flexibility did not ease. Concerning the first issue, it seems that the user innovation literature never deals with innovations to networked systems – apart from the obvious example of open source programs on the internet – where 'non-innovators' are directly and perhaps unwillingly affected by the innovations. The eFlex equipment was tied up to the energy system of the house and thus figured as a material element in many practices performed by all members of the family. It seems self-evident that innovations to a *shared* system with many users will confer negotiations and accordingly have implications for the innovative processes. Such implications do not come into light if we only study innovations to single products, which currently seem to be the focus in user innovation literature. However, the lead user innovations in the eFlex project came to have quite a literal influence on other family members' performance of practices. For example, Marie clearly resisted her husband's participation in eFlex and the results the low-temperature water had for her heat comfort and her ability to bake cakes and wash her dishes. Other examples such as Christina's opposition to the interruption of her child caring at night, or Flemming's family, who went 'crazy' when his experimentation interrupted their TV watching, are examples of the pervasiveness of practices and domains that are related to the home's energy system and thus involved in experimentation with such smart home systems.

Life paths and coupling constraints – many practices and many considerations

The positioning of practices in time and space also had implications for the experimentation that could be done with flexibility. In a practice theory perspective, daily rhythms are "achievements of coordinating and stabilizing relationships between practices" (Shove et al., 2009: 10). For example, 'doing the laundry' may be a project that consists of a closely related bundle of practices, i.e. a practice of washing clothes and a practice of tumble drying or hanging up clothes. Dislocating the washing practice in time has therefore implications for this and other 'bundles' of practices and their coordination: Charlotte, the wife of Peter, opposed Peter's desire to wash at night; she was afraid the clothes would wrinkle lying in the machine all night and, moreover, *she did not have time to hang the clothes up in the morning*. This was an issue raised by many (often wives of!) eFlex users, who would for example spend time in the morning getting the kids ready for school. Washing and drying clothes is often done successively, and separating the practices and introducing a timeslot for hanging up clothes in the morning instead of in the evening was not easy – it conflicted with other practices that were scheduled in the morning, such as getting the children ready for the day. Conflicts and considerations in relation to flexibility 'testing' were also related to the previously mentioned 'coupling constraints', since change or dislocation of a practice can impinge on several individuals' paths, as a practice can be a 'node' that several paths run through. In the eFlex study it seemed that the more actors – e.g. children and pets – there were in a household, the harder it became to be flexible with practices. Finally, constraints on experimenting with flexibility were also related to how domestic practices are structured in relation to systems or practices external to the household, as we saw in the case of René and Martin.

Conclusions

In this article, it has been shown how the quite simplified – but dominant – portrait of the smart grid 'consumer', who uses and understands technologies in an expected and uncomplicated way, misses a part of the picture. In line with von Hippel's calling, the aim of this article has been to emphasise how households are so far an unrecognised source of innovations and creativity when it comes to developing a low carbon energy system. Although there was probably a higher concentration of 'lead users' among the eFlex users than in the general population, the point remains clear: users are everyday inventors of both the technologies and the practices these are part of, and they can and do play an important role in the development of large provision systems. As Hyysalo et al write in one of the few papers that engage with this issue: "the inventive user can speed up the development and proliferation of distributed renewable energy technologies… through their alternative designs" (2013b: 490). Instead of keeping supposedly 'ignorant' publics out of the development process "they should be seen as valuable and generative to the innovation of smart grids" (Schick & Winthereik, 2013: 96). The interpretive flexibility of the smart grid is still great, and multiple roles for the householders can be constructed – e.g. the 'innovator role' that has been sketched out here. Continuing the same policies and scopes for user studies, which reproduce an old notion of the 'demand side' (Wolsink, 2012), may lose sight of the negative energy impacts the 'consumer role' could have (Nyborg & Røpke, 2011).

Furthermore, the second aim of the article has been to demonstrate that the current marketing literature's approach to understanding and 'exploiting' user innovators could benefit from STS research. This body of knowledge provides a better understanding of "how and why new products and technological infrastructures are acquired and how they affect practices as they are absorbed into everyday ways of living" (McMeekin & Southerton, 2012: 357) – and consequently better enlighten innovative processes 'on the fringes' of the smart grid field. The previous discussion illuminates the network of practices and systems the eFlex equipment interacted with, which complicated the innovative processes. Moreover, the discussion also underlines how flexibility from households is a complex matter that involves quite a lot of considerations and inter-related factors. It points to how taking on the 'flexible consumer role' depends on much more than 'willingness' or motivational factors. Thus, a stronger STS focus would deepen our knowledge of the role that users or publics have in constructing certain sustainable transition pathways and support the basis for making policies that to a higher degree fertilise the dispersed creativity of users.

Lastly, the fieldwork demonstrated the need to promote a far more 'user-driven' roll out of heat pumps as opposed to the current technology-driven process and the 'one-size-fits-all' logic. As Hyysalo and colleagues are arguing: "It appears that supplier models do not cater sufficiently for the variation in users' homes, which leaves unexplored design space for users to focus on" (2013b: 490). Thus, there is 'room' for users to innovate on heat pumps to make them more 'user-friendly' for the entire family and more suited to different and varying contexts. Just as user-oriented innovation methods are being used to increase the value of many other products, it would perhaps be beneficial for heat pump producers to integrate innovative users more in the development of these technologies. Moreover, as I have argued in this paper, when involving innovative users in smart grid development projects we should remember also to talk to an entire household just as the eFlex project did – both to explore the 'validity' of the innovative user's' concepts, but also to be inspired by the inventive inputs of other-than-lead-users. Maybe then, we could nuance the current focus on how it is mainly the financial investment that users have to make which is the reason why Danish householders are not taking up heat pumps in the speed that policy makers and producers had imagined (Catalyst Strategy Consulting, 2013).

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12 Paper IV

12.1 Heat pumps in Denmark – from ugly duckling to white swan

Heat pumps in Denmark
– from ugly duckling to white swan

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Abstract

Over the last 10 years, heat pumps have increasingly gained attention in Denmark as an integral part of the low carbon transition of the energy system. Moreover, since 2010, the smart grid system has been highlighted as an important element in this transition. The main reason being that the smart grid enables the integration of large amounts of intermittent wind energy into the electricity system via, among other things, intelligent interoperation with domestic heat pumps, which flexibly consume the 'green' electricity. A precondition for utilising heat pumps as essential smart grid technologies, however, is that a sufficient number of homeowners actually install them. Unfortunately, last year's sales were disappointing. Several studies have investigated the 'dissemination potential' of heat pumps in Denmark, primarily through conventional market research approaches. However, there is clearly a lack of studies that take a more socio-technical approach to understanding how technologies such as the heat pump develop and how they come to have a place in society as a result of contingent, emergent and complex historical processes. This paper seeks to address this gap by exploring, firstly, the historical development of heat pumps in Denmark through an actor-network theory perspective and, secondly, by discussing the current challenges to a more widespread dissemination of heat pumps on the basis of this account. The research process reveals that heat pumps have a long and significant history in Denmark, but that this is underemphasised in the current debate about them. Furthermore, this historical account provides hints as to how we can rethink the present challenges facing the possible wider dissemination of heat pumps in Denmark.

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Introduction

Globally, the smart grid is seen as an important part of the low carbon transition of the energy system. In a Danish context, this transition mainly entails integrating more wind power into the system and using electricity for heating (heat pumps) and transport (electric cars). Therefore, residential heat pumps are considered essential infrastructure technologies in the smart grid because they are ideal for the 'flexible' consumption of an increasing amount of intermittent wind power and are well suited to deliver system balance services.

In Denmark, this attention to heat pumps has resulted in the increasing exploration of how 'flexible' heat pumps are in terms of energy consumption. In the last few years, many R&D projects have been launched that investigate various aspects of their 'smart grid readiness' and flexibility potential (Insero Energy, 2013: 5), including user studies such as the 'eFlex' project and the 'From wind power to heat pumps' project (Energinet.dk, 2012; Nyborg & Røpke, 2013).

However, a precondition for exploiting heat pumps as flexible agents in the energy system is that they are actually finding their way into peoples' homes in a sufficient number In 2010, the Danish Energy Association said they expect 300.000 heat pumps to be installed in Denmark by 2025 (Energinet.dk & Dansk Energi, 2010), and the current government has initiated a complete phase-out of oil burners by 2030 – aiming for a conversion to, among other things, heat pumps. Unfortunately, the dissemination of heats pumps has not matched expectations. Therefore, studies that explore the drivers of and barriers to a more widespread uptake of heat pumps in Denmark are arguably needed.

Until now, most Danish studies that explore this area are focused on the current status of the dissemination of heat pumps, their actual efficiency performance and the 'technical' potential for further dissemination (COWI et al., 2011a; COWI et al., 2011b; Olsen et al., 2010; S. V. Pedersen & Jacobsen, 2013), the private-economic potential (COWI et al., 2011a), the socio-economic effect of further dissemination (Rambøll, 2011), and alternative business models for selling heat pumps (e.g. EXERGI Partners et al., 2014). A limited number of Danish as well as international user studies have focused on homeowners' motivations for and obstacles to buying a heat pump, as well as their experiences with the installation process and the daily operation of the heat pump (Bjørnstad, 2012; Caird et al., 2012; Energitjenesten et al., 2012; Epinion, 2010; Heiskanen et al., 2014; Publikum Kommunikation & inVirke, 2010; Roy & Caird, 2013). A few studies have taken a more qualitative approach to studying users and the dissemination of heat pumps by focusing on, for instance, the development of new comfort practices and the implications for energy consumption (Christensen et al., 2011), or the domestication of heat pumps in everyday life and the user innovations made to them (Hyysalo et al., 2013b; Juntunen, 2014; Nyborg, in progress).

Nonetheless, there is a lack of studies that embrace a more socio-technical approach to understanding how heat pumps are developing and gaining a place in society as a result of contingent, emergent and complex historical processes (although see e.g. Kiss et al., 2012; Nilsson et al., 2005). Notably, heat pumps in Denmark have not received sufficient attention in this regard. Within the field of science and technology studies (STS), it has long been argued that existing technological solutions or systems that fulfil societal functions are not dominant *because* they have an inherent technological supremacy or *because* they reflect efficient market processes. Rather, they are 'configurations that work', i.e. they are a result of the co-evolution of several heterogeneous elements such as markets and user practices, cultural values, policy and regulation, techno-scientific knowledge and infrastructures, etc. (Geels, 2002). The transformation of socio-technical regimes such as the energy system is very challenging, as these regime-configurations are often path-dependent and stabilised by lock-in mechanisms such as sunk costs and vested interests (Unruh, 2000). The current 'smart grid heating' transition in Denmark needs to be seen in relation to such dynamics.

The theoretical framework for this paper draws upon the STS literary tradition, but focuses specifically on actor-network theory (ANT). Not only does ANT focus on the relations between heterogeneous elements, but also issues of agency, controversy and power in the development of technological systems and scientific facts (Callon & Latour, 1981; Callon, 1986). In this perspective, it is the *relations* between entities such as artefacts, 'facts' and human identities that take centre stage; it is only through these relations that entities exist (Karnøe, in progress). A specific focus in this ontology is on the translation process, i.e. 'the capacity of certain actors to get other actors – whether they be human beings, institutions or natural entities – to comply with them', which 'depends upon a complex web of interrelations in which Society and Nature are intertwined' (Callon, 1986: 201). Such processes often entail struggles and resistances to being 'enrolled' in another actor's action program; that is, anti-programs are formed. Thus, during controversies over scientific 'facts' and technological developments, 'the intervening actors develop contradictory arguments and points of view which leads them to propose different versions of the social and natural worlds' (Callon, 1986: 199-200). An actor grows stronger, the more 'bodies, materials, discourses, techniques, feelings, laws, organisations' can be translated and enrolled in their network and the more 'relations he or she can put in… black boxes' (Callon & Latour, 1981: 284). Thus, the more durable and 'unquestioned' the relations and 'facts' are, the more the actor-network develops into a macro-actor.

The dissemination of heat pumps in Denmark is accordingly not a matter of single factors such as the users' 'investment willingness'. Rather, it is due to a range of factors such as already-established and path-dependent structures as well as controversies and power struggles between actor groups over, for instance, defining the meaning and value of the heat pump, and the actors' strategic work invested in aligning actors and interests. However, it is not only the current controversies that are relevant, but also the past struggles and alliances, which defined the type of relations that can be made today and which provide the frame for analysing the current situation.

Making an actor-network based account of the history of heat pumps in Demark thus also gives an indication of the types of alliances that are needed in order for the heat pump to become a macro-actor in the future. This perhaps requires that the nascent relations currently being built become stable and durable. The research conducted for this paper has revealed the compelling history of heat pumps in Denmark, a history that is generally ignored or unknown in the current debate about them. Among other things, it elucidates why heat pumps have not become a macro-actor today like wind energy has, even though Danish heat pump manufacturers once had a leading position in Europe in terms of technological development – and despite the fact that both heat pumps and wind energy started out as 'ugly ducklings' 40 years ago. Although heat pumps have recently become popular, they are still far from becoming the export success story and white swan that wind energy has developed into.

Thus, this paper sets out to answer the following research questions:

- Why was the heat pump's substantial potential to 'green' the Danish energy system not realised a long time ago?
- What can be learned about the current barriers to heat pumps by looking at its history in Denmark and the struggles and resistances that have been part of its development? How are current issues related to that? Have the barriers been overcome?
- What is the probability that heat pumps can be disseminated and become a macro-actor in the future? What other perspectives need to be discussed?

The empirical material for this paper is based on 10 interviews with actors who have been or are related to the heat pump field as well as desk studies of current and historical reports and documents related to heat pumps in Denmark. This study also draws on 24 interviews with homeowners enrolled in two recent heat pump/smart grid demonstration projects: the 'eFlex' project and the 'From wind power to heat pumps' project.

In tracing the history of heat pumps in Denmark, focus has mostly been put on small, electrically-driven ground source heat pumps or air-water heat pumps, as they are currently being discussed as a replacement for oil burners outside areas of collective supply. However, over time air-air heat pumps have also been promoted as relevant for the conversion of electrically-heated houses, including summerhouses. These three types of heat pumps mainly exploit 'low temperature' heat from the sun, which is stored either in the ground or the air, and use electricity to compress it to a higher temperature through a refrigerant circuit system. Through this process, around 3,5 to 5,5 kWh of heat are produced every time just 1 kWh of electricity is used. The heat is either delivered to a central heating system, used to produce hot water, or sent directly to the indoor air.

Having introduced this paper's research question, its theoretical framework and the methods for its empirical knowledge production, the current situation in Denmark concerning heat pumps is presented next, followed by an actor-network based historical account of the development of heat pumps in Denmark. Finally, this account is discussed in relation to the current situation, and the probability of having a heat pump 'fairy tale' in the future is considered.

Heat pumps – today's political darling

On 2 October 2013, the Association of Manufacturers of Heat Pumps in Denmark (AMHP) held a well-attended conference dubbed 'Heat Pump Day', which they organised in collaboration with, among others, the Danish Energy Association. The programme listed a variety of different speakers who had a relation to heat pump development in Denmark. This included such nobility as the general secretary of the European Heat Pump Association and the Minister for Climate, Energy, and Buildings, Martin Lidegaard (R).

At conference, particular focus was put on the role that heat pumps have in Danish Energy Policy. The minister was keen to assure the audience that he saw a very significant role for heat pumps in Denmark as he started his presentation: 'As I was just saying on the way from my new Tesla – by the way, a really cool electric car I must say! – the heat pump is one of my absolute darlings.'

His love for heat pumps, the minister explained, was sparked by the energy agreement the government reached in parliament 18 months prior to the 'Heat Pump Day'. According to this agreement, Denmark should double its investments in energy efficiency, double the share of renewable energy in the energy system by 2020, and then 'construct the smartest and most modern electricity system in the world.' The heat pump plays a crucial role in all three overall objectives, he emphasised, since 'it's effective, it can help us balance renewable energy and can even be used proactively in relation to the future smart grid.' Moreover, the minister pointed out that 'it's something that people can understand, you can afford to buy it as an ordinary homeowner [and] you can see on your bill what you get out of it.' In short, there are only good reasons for promoting heat pumps, the minister said. Accordingly, the government supported this promising technology in several ways by, for instance, reducing taxation on electricity by introducing a quality assurance scheme for installers of renewable energy technologies and by initiating the phase out of individual oil burners.

However, despite the political enthusiasm and high expectations, which the minister embodied that day, heat pumps are not really finding their way into Danish homes 'at the speed that is desired and was expected', as recently expressed by the Danish Energy Association. The association assessed that there could be a total potential of 600,000 heat pumps in Denmark as an alternative to 'fossil fuel heating forms' (Catalyst Strategy Consulting, 2013), i.e. individual oil and gas burners. However, the current annual sales figures are not encouraging if Denmark is to reach such a goal in time to meet the vision of being 100% independent of fossil fuels by 2050.

Although the sales of air-water heat pumps have increased moderately in Denmark over the last few years, the sales of other heat pump types, such as ground source heat pumps, have conversely dropped and resulted in an overall 7% reduction in heat pumps sold in 2013 compared to the year before (L. Andersen, 2014b). Thus, with only around 5000 units, i.e. ground source or air-water, sold per year, there is a long way to go to meet the abovementioned target. The Energy Agency's statistics show that by 2012, approximately 30,000 air-water and ground source heat pumps and 80,000 air-air heat pumps had been installed in Denmark. According to the Danish Energy Association, the few thousand heat pumps currently being installed per year only amounts to 5% of the potential amount of heat pumps that could be installed per year (Catalyst Strategy Consulting, 2013) and compared to Sweden, Norway and Finland the diffusion of heat pumps is modest. For instance, whereas 95,000 heat pumps were sold in Sweden in 2012 (includes six types of heat pumps), the number was only a little more than 30,000 in Denmark. In total, the Danish market is 4% of the total European market (Nowak, 2013).

It seems that the heat pump is not everybody's *absolute darling* in Denmark. Despite the 'political' effort that has been made to promote heat pumps in recent years and their many obvious qualities, as emphasised by the minister, it is perhaps strange that the initiative has not succeeded. However, things are not as simple as the minister's statement, 'it is something that people can understand, you can afford to buy it as an ordinary homeowner [and] you can see on your bill what you get out of it'; in fact, the statement is rather contested. While there are many people in Denmark who benefit from the production, trade and use of heat pumps and most actors agree that the heat pump is a core technology in promoting energy savings, helping the smart grid along and combating issues of climate change, the picture is obviously more complex than the minister is indicating.

Actually, it is *not* always easy to understand and use a heat pump. As one of our homeowners expresses it: 'the heat pump itself out there is a little bit hard to adjust… I don't think the manual is very user friendly…' or as the wife of an enthusiastic heat pump owner proclaimed, 'I really don't understand what's going on in this house…', concerning her husband's heating experimentation. Moreover, a heat pump is *not* something an 'ordinary homeowner' can necessarily afford. A much-debated issue in Denmark has been the enforced oil burner phase out, since most of the houses on the outskirts of Denmark, where the collective supply does not reach, have such a low market value that it is simply not possible to get a loan for a heat pump. Finally, the apparent savings on the energy bill or clarity concerning 'what you get out of it' does not exist for everybody – neither for the installers of heat pumps nor for the homeowners. Because while the heat pump installers in Denmark are drowning in costly 'green' training programmes, which may not pay off due to a lack of demand, for homeowners the apparent benefits such as savings on the energy bill do not always meet expectations. While the majority of people enjoy savings from installing a heat pump, there are also examples of heat pump installations that do 'not run properly' and have become 'a very costly affair', as one woman expressed it. This can occur on account of the heat pump not being installed or dimensioned properly or the homeowner being incorrectly advised as to the suitability of a heat pump for their house.

Accordingly, the transformation towards 'smart grid heating systems' involves a variety of interacting elements – domestic practices, policy and regulation, already established infrastructure, etc. – as well as differing meanings, rationales and colliding 'action programs' and anti-programs, all of which makes the dissemination of heat pumps a complex affair. In other words, the 'uptake' of heat pumps is not just a question of developing the 'best' technologies and informing homeowners of their 'apparent' benefits. Being attentive to such relations and controversies, as illustrated above, also elucidates why heat pump dissemination was not 'realised' a long time ago, even though they have a long history in Denmark and seem like an obvious element in a contemporary sustainable energy system. As demonstrated, heat pumps have recently become fashionable in relation to the smart grid – being associated with the nifty Tesla – but while the current political enthusiasm towards heat pumps is somewhat new in Denmark, the controversies surrounding them are not.

A History of heat pumps in Denmark

1950s: The first seeds

Theoretically, any refrigeration system is a heat pump and the refrigeration industry has a long history in Denmark. Perhaps the story of the heat pump begins in 1830, when the Frenchman Sidi Carnot first developed the principles of thermodynamic circuit processes that both refrigerators and heat pumps were later built on. It could also be traced back to 1879, when the world-famous brewer J. C. Jacobsen became the first Dane to import a refrigeration system for his Carlsberg brewery to Denmark (Aagaard, 1999c), which marked the beginning of a flourishing compressor and later refrigeration and thermostat industry in Denmark.

However, in practice, it was not until the 1950s that the first pioneers in Denmark really started experimenting with heat pumps. One of them was professor Jens Ehlert Knudsen from the polytechnic college in Copenhagen. Besides his temporary professorship, he had also been hired by NESA, the biggest electricity company in Denmark, to establish a research department at the college, which at the time was quite unusual for such a traditional sector (Bach, 2007). In two staff villas in Copenhagen, the research department experimented with ground source heat pumps. Their setup consisted of a number of vertical tubes placed in two concentric circles at a depth of between 10 and 15 meters. However, already after a few years their heat performance was poor, and it turned out that the outer tubes had almost created a permafrost condition in the soil surrounding them, which prevented heat uptake in the inner circles. In the mid-1960s, the heat pumps were dismantled and the experiment was discontinued.

1970s: Energy crisis and new plans: kick-off

Probably due to the low prices of fossil energy, not much generally happened in relation to the development of heat pumps in Denmark until the international energy crisis in 1973/1974,, when the Yom Kippur war in the Middle East resulted in the trebling of oil prices and an embargo on several countries including Denmark. This led to a massive effort to reduce Denmark's energy consumption and its dependency on imported oil and gas through energy saving subsidy schemes and many campaigns and research programmes were initiated (Aagaard, 1999c).

In august 1974, an energy research programme for heat pumps was, for instance, granted DKK1,4m by the former Ministry of Trade. By that time, the practical experience with heat pump installations was rather limited in Denmark. In the preceding twenty years, only around 200 heat pumps for single-family homes had been installed and 'a large share of these installations have in this same time period either been put out of operation or are functioning very unsatisfactorily' (Westh, 1977: 102). The programme ran until 1977 and investigated various technical issues in relation to heat pumps such as heat transfer conditions in the soil and air and the suitability of existing heat distribution systems for low flow temperatures. Jørgen Gullev, who as a young civil engineer had been employed in NESA's research department (and later became marketing director and vice president), was part of an advisory group for the programme. During the programme, he collaborated with 'soil experts' and learned that he and Jens Ehlert had misunderstood what the energy source actually was when they experimented with heat pumps in the 1950s. It was not 'geothermal heat' they should utilise but rather stored energy from the sun through horizontal tubes at around 80 centimetres depth.[ix] Thereafter, the question of which type of renewable energy the heat pump was actually drawing on was continuously debated.

In April 1976, the Danish Energy Agency was established to administer the new enhanced political focus on energy and in May the Minister of Trade, Erling Jensen, presented the first comprehensive energy plan for Denmark, 'Danish Energy Policy 1976' (DE-1976), which had three main points. The first was to convert from oil to coal and other alternative energy sources, mainly nuclear power; the second was to establish a nationwide gas grid with natural gas from the North Sea; and thirdly, thorough heat planning should be done in all counties and municipalities for the purpose of energy savings (Meyer, 2000).

Grass roots emerge – heat pumps too

The official energy plan also pointed to the possibility of introducing renewable energy in the system, but renewable energy only played a modest role in the plan, covering only 4% of primary energy by 1995. Meanwhile, opposition towards nuclear power was growing in both the broader population and among a small group of researchers from physics and engineering departments who had started working with different issues within energy planning. These researchers were united in their belief that Denmark could have a reliable energy provision system without the utilisation of nuclear power. During the summer of 1976, they drafted a counter plan, which excluded nuclear power, to the official energy plan and argued for a more modest growth in energy consumption and for renewable energies to cover 12% of the primary energy provision (Meyer, 2000).

The alternative plan got a lot of attention due to excellent press coverage, which the two grass root organisations OOA (the Organisation for Information on Nuclear Power) and OVE (the Organisation for Renewable Energy) had helped along. These organisations had been started in 1974 and 1975 respectively and basically wanted to stall the implementation and utilisation of nuclear power, which was seen as representing 'alienation, concentration [of power] and the risk of sabotage' (Beuse et al., 2000: 25) as well as promote the utilisation

[ix] Placing the tubes horizontally has been far more common for ground source heat pumps in Denmark. In Sweden, it is, however, common to place the tubes vertically, i.e. from 30 to 300 meters depth. The tubes then utilise both solar heat and geothermal heat. Traditionally, geothermal energy has been exploited by retrieving hot water from a depth of 1,5 to 4 km (Aagaard, 2003).

of renewable sources through information campaigns and the lobbying of politicians. It meant a lot to the grass roots movement to 'do-it-yourself' and build their own wind turbines or solar heat panels. Renewable energies were especially well suited for small-scale energy production, which was built and maintained locally and which would promote community building**,** participatory democracy and prevent estrangement. OVE in the little town of Thorsø – they called themselves TOVE – for instance, organised study circles and open-house arrangements, where people would discuss the possibilities of building their own wind-turbines, solar heating installations and small biogas-plants and demonstrate their self-built installations. The group of self-builders were farmers, craftsmen, etc. and 'all around 25 to 40 years old with zest and a pioneering spirit' (Beuse et al., 2000: 26). As one of the members recalls, '[t]his was a time when for little means you found bits [and pieces], so you could build your own solar collector. Perhaps not a very effective solar collector, but they were cheap and worked for several years. And then you had done the work yourself' (Beuse et al., 2000: 26). The movement was thus also part of a wider critique of established society: 'It was often discussed how utilising renewable energy resources and organising energy provision in accordance with principles of decentralisation and democracy held the utopia of future society' (Beuse et al., 2000: 40). Due to the resistance in the population against nuclear power, in 1976 the Danish Parliament decided to postpone its introduction, and in 1985 they finally agreed that Denmark should not have nuclear power (Meyer, 2000).

There were also a few pioneers that built heat pumps in the years after the oil crisis and several more or less imaginative projects appeared, for example, the 'energy fence'. Here, the heat absorbers for the heat pump consisted of an aboveground fence of pipes around the garden. Another was 'the energy well', which was designed by the engineer N. K. Knudsen. He believed it preferable to extract heat from the soil but did not want his entire garden dug up. Accordingly, he devised a system where looped tubes were put in the ground from a well in the form of a star (Beuse et al., 2000: 342). At the time, heat pumps were often tailor-made and very expensive. The first mass-produced heat pump in Denmark was developed and put on the market in late 1974 by the 'heat pump pioneer', civil engineer Marc Fordsman, who was a consultant for the newly started company Danish Heat Pump Industry (DVI) (Beuse et al., 2000: 343). He had already collaborated for some time with the electricity companies in Southern Jutland, which were pushing the development of heat pumps (elnyt, 1975). The DVI company chose to use the ground as an energy source, and the type of installations they produced were subsequently named 'ground heat', which led many to mistakenly believe that this type of heat pump took energy from the earth's core, i.e. geothermal heat. Although this type of heat pump resembles the ground source heat pumps we have today in individual households with water-based heat emitter systems, many other types of heat pumps have been developed and then disappeared, such as ground/air systems (ELRA orientering om elvarme, 1972).

Heat pumps not part of renewable energy utopia

The grass roots movement, however, was not in favour of heat pumps. They did not consider them a renewable energy technology and very clearly preferred technologies that utilised sun or wind more directly, such as wind-turbines and solar heat installations (Beuse et al., 2000: 41). There were basically two problems with the heat pumps. Firstly, although the heat pumps utilised renewable sources, they still needed some sort of fossil-based propellant such as electricity, gas or diesel, which at the time was regarded as 'black energy'[x]. Moreover, it was argued that their energy saving potential was not 'real'. In the magazine *Renewable Energy* from 1981, an article on heat pumps argued that since the conversion efficiency for electricity

[x] This is a direct translation of a Danish expression – 'black' indicates the colour of the fossil fuels and moreover signals something 'not positive'

production at a power plant was normally stated to be one-third at the time (which does not, however, include CHP's, which were not widespread at the time), and since heat pumps 'in their marketed forms use electricity, it is clear to see that unless the COP value is bigger than 3, we are just back at the starting point!' (Beuse, 1981: 13). It should be noted that this magazine was published by OVE. The article also stated: 'At the moment, the situation with practical experiences with COP values of 1,5 to 2,5 is that the more heat pumps there are, the bigger energy consumption in the form of electricity' (Beuse, 1981: 13).

Secondly, established institutions such as the electricity companies and the Association of Danish Electricity Companies' Investigation Department (DEFU) were interested in, and developed, the heat pumps and they – as explained in the abovementioned article – certainly did not complain about the 'situation'. It was also stated that there had not been any critical voices from the electricity companies in relation to heat pumps, 'as opposed to wind turbines that are actually a positive contributor energy wise' (Beuse, 1981: 13). Furthermore, the article emphasised that these dominant actors:

> '…are heavily engaged in the development of heat pumps and are also represented in the steering committee that is to administrate the funding, which is set aside for heat pump development in the Ministry of Energy's Research programme. In fact, the interest from the electricity companies is so big that they have taken on a guarantee system for the installations to help the market get started! Who said you should let the fox guard the chicken?' (Beuse, 1981: 13).

Thus, the heat pumps did not hold the utopian promise in the way the 'true' technologies did, since these technologies were endorsed by dominant institutions and interests and since they would in effect reproduce existing structures in society. In the opponents' view, heat pumps 'promoted the need for further expansion of power plants and brought nuclear energy closer' (Willumsen, 1993: 5).

1980s: The heat pump test station and opposing programs of action

Heat pump station and regulation – an actor is defined

In 1978/1979, another international oil crisis put even more emphasis on developing renewable energy technologies, and in 1979 the Ministry of Energy was established, which took over issues of energy from the Ministry of Trade. The governmental R&D energy programmes, which had been initiated after the first oil crisis, were continued and the wind, sun and biomass programmes received large funding. Also in relation to heat pumps was the establishment of a comprehensive research programme in 1980, which lasted until 1990. During this ten-year period, over 76 heat pump projects were completed and reported (Poulsen, 2011).

In 1979, the government further adopted the 'Law on State Subsidies for the use of Renewable Energy Sources', which made it possible for households to get a subsidy when establishing energy installations that utilised 'solar energy, wind power, ground heat, biogas, straw and other comparable renewable energy sources' (Boligministeriet, 1979). The Ministry for Buildings administered the law, and the subsidy rate was 30% of the installation cost. However, in 1981 the law was superseded by a subsequent law that was under the authority of the new Ministry for Energy and which declared that 20% of installation costs could be granted to solar heating installations, wind turbines, heat pump installations, biogas plants, compost heating facilities and hydro power facilities. The Danish Energy Agency administered the subsidies and was further obligated under this law to fund the establishment and operation of a number of 'test stations'. These were established for each 'new' energy technology, and their purpose was basically to test and standardise the different technologies so that public funding was not spent on 'ineffective' or badly developed technologies (Meyer, 2000). The heat pumps that were tested and met certain standards were put on a list of approved heat pumps that could obtain funding.

The civil engineer H. C. Aagaard was hired to start up and run the test station for heat pumps, which in the spring of 1981 was placed at an independent institution called Teknologisk Institut (Technological Institute, TI). During the first couple of years, a wide variety of projects were undertaken to standardise, for instance, issues of dimensioning, the depth of the tubes in the ground, how far apart the tubes should be, the length of the tubes in relation to the size of the house, and so on. In short, the test station was mandated to establish the minimum requirements for the heat pump's performance, operational reliability and service life. This work was desperately needed since none of these processes were in place at the point when the subsidy law came into effect, and the engineers at TI had to work fast.

Heat pump program, concerns and anti-programs

Aagaard developed information courses for the so-called energy offices. These offices were established in 1975 as a collaboration between OVE and OOA. In the first couple of years, the energy offices were placed at local folk high schools[xi], and their aim was to inform the public about the possibilities of new renewable energy technologies as well as run courses, for instance, in how to build wind-turbines and establish wind-turbine cooperatives. Later, they became more formally organised and spread out nationwide. Furthermore, they began to receive public funding – especially because they also began to take on the task of informing and guiding the public about the various subsidy-schemes the government had introduced to support renewable energy installations in households (Beuse et al., 2000: 64), including heat pumps. However, the energy offices often had a negative view of heat pumps, and the majority of them clearly preferred sun, wind and biomass. The exact reason for this was unclear to Aagaard, but it was often 'the ones with blue cloth diapers'[xii] that questioned heat pumps the most. These belonged to a group of people that were powerful in forming public and political opinion and had already succeeded in stopping the nuclear power project in Denmark. At an energy meeting in The Danish Society of Engineers in 1977, the newspaper *Information* quoted Jørgen Gullev saying, 'It is activists and watercress-eating Gold Coast socialists that together with OOA are dominating the picture' (Meyer, 2000: 84).

However, the OOA and OVE were not the only actors that had concerns in relation to heat pumps; besides the test station standardisation work, there were also other regulatory issues that had to fall into place during these first couple of years. The Ministry of Environment and the water utilities authority were, for instance, concerned about ground source heat pumps and their possible contamination of the groundwater, which had always been seen as an invaluable asset in Denmark. The fear was that if a tube leaked, the fluids – which could contain e.g. antifreeze liquids – would seep through the soil. Therefore, a decree on ground source heat pumps came into effect in 1981, which, among other things, stated that heat pumps with both vertical and horizontal tubes should be placed at least 300 meters from any

[xi] In Denmark there are about 70 different folk high schools and their purpose is to offer non-formal adult education. See more: http://www.danishfolkhighschools.com
[xii] Wearing cloths diapers as a headscarf indicated some sort of sympathy for the left wing youth rebellion and feminists movement in the 1960s and 1970s

public water supply plant. This decreased the number of households that could be granted permission by the municipality to install a heat pump.

In Aagaard's view, the emerging concerns, protests and reluctance from several powerful actors was part of the reason that the subsidy for heat pump installations was soon reduced. In 1982, the subsidy for heat pumps was reduced to 10% of installation costs, whereas subsidies for other sources of renewable energy – solar heat, wind turbines, biogas installations, compost heating facilities and hydropower facilities – were raised to 30% of the installation costs (Lovtidende A, 1982). However, the establishment of a stronger program at that time played perhaps an even bigger role in the emerging political and regulatory disfavouring of heat pumps: the natural gas project.

Natural gas – an emerging macro-actor

The first Danish energy minister, Poul Nielson, who stepped into office in 1979, was a devoted proponent of natural gas, and he secured investments in the gas network. A heat plan committee consisting of governmental authorities, counties, municipalities and the electricity sector had already been established in 1977 to concretise how and where natural gas should be implemented in Denmark. This would happen through a so-called 'area delimitation' process, whereby the country was divided into four areas: one area with natural gas; one area with district heating (DH) and combined heat and power (CHP); one area where further investigations were needed in relation to the possibilities for natural gas or DH; and, finally, 'area 4' which would have neither natural gas nor DH. Based on the work of the committee, both a heat planning law and the natural gas project were adopted in 1979, together with the establishment of the Ministry of Energy (H. Ø Pedersen, 2007). Collective heating in the form of natural gas and DH/CHP were important elements in the heat planning law. The development of DH systems in Denmark had already been going on since the 1930s in Copenhagen – based on waste heat from local power production – and had spread to most other large cities in Denmark throughout the 1950s and 1960s (Odgaard, 2014). In comparison, not one natural gas pipe had been laid at the time the project was adopted, but the entire system had to already be in place by 1984 and became one of the biggest and most expensive, state-financed construction projects in Denmark.

Meanwhile, in 1981 a new energy plan was presented, which was basically a continuation of the former plan: cutting down on oil imports and decoupling energy consumption from economic growth. However, the increasing focus on energy savings in that period led to a decline in demand for heat while oil prices started falling again, which meant that the dissemination of natural gas did not proceed as expected. One of the means to secure the huge public investment in the natural gas project was to extend the gas network all the way to the individual household so that gas would be used in individual boilers (Meyer, 2000). Moreover, it became mandatory for households to connect to the collective systems, which was enforced in 1982. Furthermore, whereas oil, coal and electricity taxes had increasingly been raised since 1977 to promote savings, oil and coal taxes were raised on a large scale again in 1985 and 1986 to counter the falling oil prices, while natural gas was not taxed (F. G. Nielsen, 2006; Stokholm, 2014).

The fight between two emerging programs of action

At the same time, the emerging heat pump industry experienced a sudden decrease in sales, which had otherwise seemed very promising from the end of the 1970s to the start of the 1980s. The first subsidy law from 1979 made DKK 50m available for the scheme, which attracted a lot of attention. In a newspaper article from October 1979 with the title '50 million kroner torn away in less than two months: in line to apply for money for ground heat' (Rosenberg, 1979), it became clear that heat pumps were indeed very popular among the applicants – the total amount applied for heat pumps (DKK 14,7m kroner – mainly ground source) topped the applications for the six renewable energy installations, which also included straw burners (12,7m), wind turbines (10,3m), solar heat (5,6m), wood burning (5,5m) and biogas (0,1m).

However, demand declined from around 2,000 units sold in 1982 to a few hundred sold just a few years later in 1986. As Ole Willumsen from DEFU wrote in the action plan 'The Heat Pump's Possibility in the Future' in May 1986, which was sent out to various stakeholders, 'undeniably, the development does look quite disastrous' (Willumsen, 1986: 1). Ole Willumsen blamed the inconsistent quality of heat pump installations, the lack of marketing and promotion of heat pumps, and the fluctuating subsidy schemes and oil and electricity prices. Moreover, a new decree of the subsidy law imposed in January 1985 had entirely removed the subsidy for 'smaller, electrically powered heat pump installations' (although it was reinstated again in 1988), whereas the other renewable energy installations continued to be subsidised. Willumsen pointed to several policy options that would 'avert the disaster', such as bringing down the costs of heat pumps, supporting bigger operational savings by taxing electricity at the same rate as fuel oil[xiii] , a quality assurance scheme for heat pump installers, a safety net for customers – i.e. a 10-year extended guarantee – and better information to households. The quality assurance scheme and the extended guarantee were already being discussed with the TI, the AMHP and the Ministry for Energy respectively.

Nonetheless, the heat pump stakeholders considered the emerging natural gas network and the tax exemption, as well as the mandatory connection to it, one of the biggest barriers to the dissemination of heat pumps. A few months after Ole Willumsen's 'warning of the coming catastrophe', Jørgen Gullev wrote an article titled 'The heat pump has now become energy policy's 'Black Pete'' in the Danish Energy Magazine. In the article, he pointed to the recent political commitment to more low-energy building projects and argued that although a construction company that undertook some of these projects designed the houses with heat pumps, in practice many of them would be forced to install natural gas. In order not to obstruct the development of low-energy housing, the municipalities had been authorised to dispense with the mandatory connection rule, but in practice it was difficult to get the dispensation. This was only given to houses that had a very small heating demand, i.e. below 30 gigajoules (GJ). (Today's low energy houses are approximately 26 to 27 GJ). This threshold had been approved by the city council on the basis of calculations from The Natural Gas Company of the Capital Region (HNG), which had estimated that 27 GJ (700 m3 gas) was the threshold of a supply per household that would be profitable to them. 'This traffic', Gullev wrote, 'in practice makes it impossible to build low-energy houses with heat pumps and the Energy Association confirms that 'the 700 m3 rule' is not viable' (Gullev, 1986: 38). The example used was two low-energy houses in the small village of Snoldelev, both of which had recently been refused dispensation by the municipal council because they had a heating demand of 35 GJ. Soon, however, a new agenda would be taken up in the heat pump action program in an attempt to grow stronger.

[xiii] Electricity was taxed 60-70% 'harder' than oil, but had recently in relation to the tightening of energy taxes in 1985/1986 gone from being taxed 300% harder, so he did not see a further levelling to be realistic

1990s: From independence from imported oil to global warming

Global warming becomes an issue

In 1988, a climate conference held in Toronto called for the stabilisation of global CO2 emissions by 2000 and a subsequent reduction of 20% before 2005 as an international objective. These events set the tone for the third official Danish energy plan, which was presented by the new pro-environmental energy minister, Jens Bilgrav Nielsen, in the spring of 1990. The new plan was entitled 'Energy 2000 – Action plan for sustainable development', and the new minister believed it was of great importance to develop a sustainable energy system, not least because of the threat of man-made global warming. In line with the recommended international targets, the Danish plan aimed for a 20% reduction in CO2 emissions and a 15% reduction in energy consumption compared to the 1988 level – at the time, one of the most ambitious national energy policy targets (Meyer, 2000).

However, this new 'sustainable' political direction did not signal a break from the political headwind that heat pumps had experienced for almost a decade, since there was no ambitious proposal for them in the new plan. In addition, a ban on electric heating had come into effect in 1988 and taxes on electricity had been further raised in 1989, which strengthened the link between electricity and an undesirable direction for the energy system. Moreover, the 'Renewable Energy Council' (REC) was established in the fall of 1990 as a replacement for the Renewable Energy Steering Committee and was to function as an advisory board for the Energy Agency. In relation to the REC, specific technical boards were established for each of the three renewable energy sources: biomass, wind and sun; notably, heat pumps were not represented on any of the boards. The committee worked hard to promote the represented energy sources and, among other things, advocated strong solar heat campaigns, identified the advantageous of offshore wind-turbine parks and suggested further research in, and experience with, hydrogen technology and biomass facilities (Meyer, 2000).

The fight to be defined as renewable energy continues: ally with global warming

Thus, heat pumps were increasingly 'falling between two stools' and no influential actors were promoting them. OVE and the grass roots groups continued their opposition against heat pumps and the political system did not really support it. However, the new sustainability agenda presented a new opportunity for heat pumps since renewable technologies were increasingly framed as a matter of bringing down CO2 emissions – as opposed to just securing independence from oil or opposing centralised electricity systems. In this context, heat pumps really stood a chance: not only because of their energy efficiency, but also because the increasing amount of wind energy in the otherwise 'black' electricity system provided a crucial legitimisation of heat pumps. However, the 'CO2 friendliness' of heat pumps was still very controversial, and the Energy Agency took the position that the change in focus from independence from oil to a cut back on CO2 emissions actually weakened the heat pump (EnergiNyt, 1993).

In the fall of 1990, Aagaard argued in a memorandum called 'The use of heat pumps as an element in energy planning' that the current focus on protecting the environment and avoiding 'the green house effect' meant that abroad the heat pump was increasingly being seen as an important element in energy provision planning. However, in Denmark, despite being at the forefront internationally in relation to renewable energy and energy savings, the sales numbers were disappointing. In the coming period, therefore, the heat pump manufacturers (AMHP) and the test station were going to have a stronger profile 'in the form of better and more focused information about the heat pump's possibilities for improving the external environment' (Aagaard, 1990: 1). The information material would, for instance, state that heat pumps were suitable as 'de-central, environmentally-friendly heating devices'; they reduced emissions of CO_2, SO_2 and NO_x; they could be used for both space and water heating; and they presented the possibility of 'environmentally-friendly and yield-increasing interoperation with, for example, wind power, solar cells, wave energy [etc.].' What presented a particular problem, Aagaard argued, was that despite the significant amount of exporting, 'the home-market is way too small to maintain this leading position we have in the long run, since a reasonable domestic market is necessary for product development and the testing of new technology in practice' (Aagaard, 1990: 2).

Heat pump network too weak

A few months later, a press release from the AMHP was sent out concerning the heat pump's placement in the energy debate. In a cover letter, it was stated that the reason for the press release was that 'the heat pump as an advantageous heating form has been kept silent in the public debate for too long' (Winther, 1990). Titled 'Trade association: heat pumps are renewable energy and should be treated as such' (Varmepumpefabrikantforeningen, 1990), the press release emphasised that Danish heat pumps delivered twice as much renewable energy as the total amount of Danish wind turbines. Yet the politicians still refused to consider heat pumps as a source of renewable energy and heavily taxed heat pump owners via the high electricity taxes. The press release further argued that heat pumps should be treated the same as other renewables, so that Danish heat pump technology could become disseminated and 'benefit Denmark both socio-economically and environmentally' (Varmepumpefabrikantforeningen, 1990). For instance, it was argued that substituting oil burners with heat pumps outside collective supply areas would reduce Denmark's CO_2 emissions by 20%, which would support the energy policy goals. And economically, Denmark exported DKr120m worth of heat pumps to Sweden each year. In that year, the press release reported that 30,000 heat pumps had been installed in Sweden compared to only around 500 in Denmark.

At a Nordic heat pump conference in the city of Sønderborg shortly after the press release, it became clear that the political 'blockage' also had to do with a general ignorance of the great environmental advantages of the heat pump – mostly due to poor marketing. Manufacturers, suppliers and installers could have worked more effectively together to give the heat pump 'the position in energy plans and reports that it deserves' (Gullev, 1991). However, the political resistance was not only due to a lack of knowledge, ideology, poor marketing and a weak heat pump stakeholder group. As the former president of the 'Energy Price Committee', Professor H. P. Myrup, said at the conference: 'the heat pump has become the ugly duckling of Danish energy policy and economic sense is not exactly the bedrock on which Danish energy policy rests' (Gullev, 2007: 15).

Greening of collective systems: Natural gas and CHP grow

Professor Myrup was not alone in being critical towards Danish energy policy, and the large and expensive natural gas project, as well as its dominance over other energy alternatives, was increasingly being questioned. An editorial in the magazine *The Engineer* from January 1990 commented on a new report from the Ministry of Energy, which evaluated the finances of the project. The writer emphasised the large amount of debt the project had accumulated, the narrow focus on corporate finance and lack of a socio-economic perspective and further stated: 'it is too short-sighted to pursue an energy policy that has the sole purpose of saving the finances of the natural gas project' (Ingeniøren, 1990).

However, despite the resistance facing the natural gas project and the heat pump's attempts to 'latch on' to the sustainability agenda, the expansion of the natural gas project and district heating continued – and domestic heat pump sales remained low. During this period, wind power in Denmark also suffered from several attacks, such as the removal of a subsidy in 1988, but as opposed to heat pumps, the wind power network had grown so strong that it was no longer possible to dissolve it (Karnøe, in progress). Then, in 1993 Denmark got a new, greener government and a new Minister of Environmental Affairs and Energy, Svend Auken. He was a committed proponent of renewable energy, notably wind energy, which was a technology that became intimately related to the fight against global warming and CO2 reductions. Moreover, concerted efforts were made to 'green' energy production and reduce consumption through the increased use of combined heat and power plants, the dissemination of district heating and the use of biomass, natural gas and other environmentally-friendly fuels in both central power plants and in decentralised combined heat and power plants. However, heat pumps were not favoured during this period either and continued to be equated with 'electric heating'. Although a new decree on the subsidy law from April 1993 had raised the subsidy on heat pumps from 10% to 15%, it had concomitantly stated that subsidies should no longer be given to heat pump installations that were located in areas with collective supply or in areas that were zoned for collective supply. Conversely, biogas and solar heating installations were still subsidised in these areas at 30% of the costs (Energistyrelsen, 1993). The decision to concentrate the heat pump subsidy on area 4 was made after the Energy Agency in 1992 became aware of the 'aggressive' marketing of heat pumps in areas planned for collective supply under the slogan 'avoid district heating coercion'. Buildings with different forms of renewable heating, including heat pumps, were exempted from the duty to connect to collective supply. Moreover, a subsequent study had shown that 60% of the heat pump subsidies were issued in areas planned for district heating or natural gas, which according to the Energy Agency's assessment had lower CO2 emissions than electrically-powered heat pumps (EnergiNyt, 1993).

Natural gas dominance and heat pump resistance

The Energy Agency had discussed the changed subsidy with the AMHP, which had agreed to focus their marketing of heat pumps in area 4. In contrast, the natural gas program was also 'aggressively' trying to enrol actors in their program. In February 1994, the AMHP sent a letter to the energy minister, Jann Sjursen – who would be replaced with Svend Auken a few months later – as well as to the Parliament's Energy Policy Committee. The association protested, firstly, against the equally aggressive marketing methods of the regional gas company 'Natural Gas South', who had been sending out commercial brochures to heat pump owners, and, secondly, against the government's new 'green taxes', which were to come into effect from 1 January 1994 and which were also used as a sales argument in the brochure.

The brochure from Natural Gas South, which was attached to the letter, started out by telling the homeowner that 'the heat pump that has served you faithfully over the years is perhaps approaching its retirement age. It has namely become evident that after 10-12 years problems with the heat pump often start to arise' and 'you run the risk of being without heat and hot water'. As an alternative, the homeowner was advised to shift to natural gas and, in doing so, would get a large discount. Moreover, it was emphasised that the government's new introduction of 'green taxes' meant that the electricity price would rise between 48% and 54% up until 1998, so 'it becomes significantly more expensive to heat up your house with a heat pump… if you change to natural gas now you avoid the green taxes' (Naturgas Syd, 1994). At that time, natural gas was still exempted from taxation.

The heat pump association pointed to the monopoly status of the natural gas company and its democratically-elected board of directors and argued that it was illegal to misuse registration information to approach new customers. Furthermore, the marketing material was misleading and untrue and undermined the possibility of motivating people with electric heating to convert to heat pumps, which for them was ‘unconditionally the best alternative to reduce CO2 emissions’. Moreover, the association pointed to the ‘unfair discrimination our customers are being subjected to as a result of the CO2 taxes’ and argued that they had previously, in June 1993, documented for the minister that heat pumps in practice did not have higher CO2 emissions than natural gas and should therefor in principle be taxed similarly. Taking the Energy Plan 2000 into account, the CO2 emissions from heat pumps would become even less. In addition, they knew that the minister ‘was not unaware that heat pumps are the best alternative in areas that are not allocated to collective heat provision’ and that ‘unfortunately, we must note that the well-documented research work the manufacturers’ association has conducted and sent to the energy minister concerning the heat pump’s positive energy and environmental advantages has not led to any clarification for the industry’s future development and employment possibilities’ (J. Andersen, 1994). The minister, Jann Sjursen, replied in April 1994 that in relation to the use of natural gas, ‘it is well known that it is the government’s goal to increase connectivity to collective systems’. Furthermore, he noted that it was the Energy Agency’s assessment that despite ‘taking the expected development of more environmentally-friendly electricity production into consideration’, there was no significant difference between the CO2 emissions from individual natural gas burners and heat pumps. However, he had ‘asked the Energy Agency to consider possible initiatives towards electric heating customers outside the areas with collective supply. Here, conversion to electrically-powered heat pumps will also be considered’ (Sjursen, 1994). The solution, it turned out in 1995, came in the form of a subsidy scheme for the conversion to central heating systems. Ejlif Nielsen, technical manager in the energy company EASV, argued in a newspaper debate column in 1995 that in practice this meant a conversion to oil burners and biomass (E. Nielsen, 1995). Concerning the energy taxes, Sjursen noted that, up to that point, electricity for heating (both direct electric heating and heat pumps) had been taxed at a much lower rate than fuel oil and with the new reform would only be taxed at a marginally higher rate than fuel oil.

Technological Institute: use heat pumps as a flexible element in energy system

Nonetheless, the Energy Agency believed they had given the heat pumps a ‘helping hand’ by raising the subsidy to 15% in area 4 and by finally supporting the quality assurance scheme for installers, which Aagaard and others had been trying to establish since the 1980s. Given that the installation of heat pumps had to be somewhat more precise than other systems, such as ‘well-known’ oil burners, it required quite distinctive skills and many bad installations had been performed in the 1980s. The scheme was intended for companies that worked with the installation and maintenance of small, electricity-powered heat pumps, and they could obtain a ‘VPO certificate’ if at least one person in the company had passed a VPO course and the company had a ‘quality assurance system’. The state subsidy for heat pumps was accordingly conditioned on not only approved heat pumps, but also on it being installed by a member of VPO. This scheme was part of the government’s renewable energy action plan for the years 1992 to 1994. In relation to the renewable action plan, Aagaard had also argued for further research in how heat pumps could be included as a flexible element in energy planning, primarily in area 4. Specifically, Aagaard asserted that heat pumps could advantageously work in joint operation with, for instance, wind power, solar heat/PV, biomass and natural gas, and could thus stretch the resources, enhance the yield of the other renewable energy sources and handle the ‘overflow-electricity’, which was a result of the increased combined heat and power production and electricity savings. Accordingly, the TI got funding from the Energy Agency to investigate whether it would pay off to develop heat pumps that could be integrated into the district heating system, natural gas system as well as interoperate with other individual renewable systems such as solar heat, micro-CHP and small wind turbines. However, the district heating and natural gas companies were reluctant to get involved in the project and, although the Energy Agency officials, who were in charge of the test station activities, were committed to the project and 'the heat pump program' in general, there was no political interest in pursuing the project further.

Moreover, in a memorandum from March 1994 – called 'The status of the dissemination and implementation of heat pumps in Danish energy planning' – Aagaard argued that there were still issues, notably, in relation to the newest green energy tax mentioned above, which only affected electricity but not heating oil or natural gas. This had led to an almost complete halt in sales and a 'frustrated business that after all includes 10 Danish manufacturers with associated sales organisations as well as a larger number of installation companies' (Aagaard, 1994: 3). Aagaard also pointed to other barriers to dissemination, which were, for instance, that consumers often had trouble with the loan ceiling on their property and that consumers were unsure about whether there would be a sufficient, continuous operational saving to pay off the extra investment required.

Wind energy grows in new plan – but electricity is still unpopular

In 1996, the fourth official energy plan, 'Energy 21', was presented by Svend Auken. The previous focus on energy savings and expanding and 'greening' collective systems continued, and wind power had now been given a significant place in Danish energy policy. The Renewable Energy Council was replaced by the Energy Environment Council, which focused more broadly on the 'sustainable development of the energy system' and did not specifically promote renewable energy sources (Meyer, 2000). However, the technical boards on sun, wind and biomass were maintained, and in the Finance Act Agreement of 1997, it was agreed that a technical board for wave energy and hydrogen should also be established. In the same year, The Electricity Saving Trust was established, which aimed to promote electricity savings in private households and in the public sector. The trust started out with a campaign against electric heating, which once again supported the link between electricity and 'black energy'.

In the same year, 1996, as part of an information strategy the test station and the AMHP prepared a folder for households in area 4 since the abovementioned 1995 subsidy scheme for the conversion of electric heating in area 4 had not resulted in increased sales of heat pumps. Moreover, ELFOR conducted a market analysis that showed that knowledge about heat pumps was 'scarily low', i.e. below 2% among potential homeowners with electric heating (Aagaard, 1996: 1). Apparently, this information strategy did not result in the heat pump's breakthrough either; by 1996, sales were still low. However, the lack of dissemination was, in Aagaard's view, also due to more significant political and professional preconceptions as well as the lack of a 'holistic, long-term and coordinated optimisation of the energy system' (Aagaard, 1999a: 1). A few years later, in 1999, he wrote an article for the magazine *The Plumber*, with the title 'Will the heat pump ever get a chance?' It was based on a proposal he wrote for the new Energy Environment Council's competition about what the new 'energy saving law' should contain. In his proposal – which did not win – he once again pointed out how heat pumps would interoperate well with other renewable energy technologies in the system such as solar cells and wind energy. He further emphasised that the tax system had unfortunately 'not "wanted" to consider heat pumps on equal terms with other heating systems' (Aagaard, 1999b: 8), which effectively meant that worn out heat pump installations were often replaced with new oil burners.

2000 – 2005: The heat pump network is dismantled

Abolition of the subsidy law and test station

In 2001, the change in government led to the abolition of the subsidy law for renewable energy and the decommissioning of the test stations for renewable energy technologies. The new prime minister, Anders Fogh Rasmussen, was president of the neoliberal party of Denmark. It was important for him to break with the former environmental minister's ambitious and 'centralistic environmental politics' as well as his so-called 'energy and environment mafia'. This break also included the closure of a large number of government councils, boards and institutions, which he believed had developed into 'state authorised "arbiters of taste" that claim what is right and wrong in various fields'. He promised that the new government would undertake 'a very extensive rationalisation' with regard to the boards and the environmental field in general, including the Ministry of Environment (Rasmussen, 2002). Apparently, one of these 'arbiters of taste' was H. C. Aagaard, who left the test station when its financing from the Energy Agency was removed following the cancellation of the subsidy law. After 1 January 2003, the test station was still located at TI, albeit in a different form and on a much lower budget, which is based on a voluntary user-financed system approval scheme, i.e. a 'positive list', under the charge of Claus S. Poulsen.

2005 – 2010: Heat pumps in energy policy – replace oil burners

Heat pump campaign kick-starts interest

After several years of almost complete silence in relation to heat pumps, a few things started to happen politically. In 2005, a technical background report from the Danish Energy Agency highlighted heat pumps as both economically and environmentally viable alternatives to fossil heating forms in private households. Then, in 2007, they were mentioned in the government's new energy policy proposal, 'A visionary Danish Energy Policy 2025', as a 'renewable energy' that should be promoted as one of the means towards becoming fossil free. The government wanted to 'launch a campaign that will promote the use of energy efficient heat pumps as replacements for worn-out oil burners' (Regeringen, 2007: 4).

The campaign was launched in 2008 after the government reached an energy agreement in parliament. In relation to the agreement, DKK30m was set aside for the promotion of individual heat pumps. At the time, the opposition parties questioned the narrow focus on heat pumps as a means to reduce oil consumption for heating and asked the government to 'consider whether this is the way we get the most for our money, or if they should not be used more broadly (pellet burners, reduced heat consumption, etc.)?' (Energistyrelsen, 2008). However, it was argued that the improved dissemination of heat pumps was the socio-economically best alternative to oil burners in areas outside collective supply and would contribute both to an increased share of renewable energy in the system and secure energy savings. Consequently, the Energy Agency launched a range of analyses and initiatives, for instance, a new certification list for the most effective heat pumps, all of which would be eligible for a subsidy, as well as public information campaigns. Furthermore, a new subsidy scheme – 'scrap your oil burner' – was introduced between 2010 and 2011. If homeowners converted their oil burner to district heating, solar heat or a heat pump, they could be subsidised with 20,000 DKK (ground source) or 15,000 DKK (air-to-water). About 9000 of the 20,000 homeowners that took advantage of the scheme converted to a heat pump (Energistyrelsen, 2013).

2010 – New smart grid framing

Electricity means 'green'

Meanwhile, in 2010 the words 'intelligent energy system' and 'smart grid' had suddenly started appearing in a number of policy documents and white papers, and a clear link between this modernised electricity system and heat pumps was being established. Although heat pumps started to appear more in governmental policy plans in 2007 and in 2008, their role and meaning started to change around 2010. They shifted from being seen as separate units to being seen as an integral and beneficial part of a collective system. They were no longer merely associated with a means to increase the share of renewable energy and help Denmark become free of fossil fuels, but had also become one of the dominant means with which to take advantage of an increasing amount of intermittent wind energy, which threatened to destroy the stability of the energy system. Electricity was increasingly related to something 'green' and 'pure' based on its relation to wind energy, therefore enabling the same characterisation of heat pumps with such qualities. The emerging association with 'the smart grid' strengthened the heat pump's position and identity as green and useful not only for energy efficiency or CO2 emissions, but also as invaluable and 'flexible' consumers of green electricity. Even the 'hereditary enemies' of heat pumps such as OVE had to accept them 'in their new form', although they still argued that the 'roll out' should be controlled. In a hearing for the national action plan for renewable energy that was developed to meet EU's directive from 2009 on the use of renewable energy sources, OVE gave the following suggestion:

> '[T]hat the heat pump expansion only be increased in pace with the increase in renewable energy in electricity production, with the guideline that electricity consumption from heat pumps and transport should increase at a slower rate than electricity production from renewable sources' (OVE et al., 2010: 65)

In 2010, the government's Climate Commission published its report, 'Green Energy – the road to a Danish energy system without fossil fuels'. The commission had been established in 2008 to come up with ideas for how Denmark could become fossil free in the future. The report emphasised that the energy system should become more 'intelligent' and that 'intelligent electricity meters, time-controlled recharging for electric cars and heat pumps in combination with heat storage systems are just some of the technologies required to exploit periods with maximal wind production' (Klimakommissionen, 2010: 9). Strikingly, as Claus S. Poulsen noted, 'the word 'heat pump' is included 55 times in this report. Not too bad considering that heat pumps have historically struggled to even be characterised as renewable energy' (Poulsen, 2011: 51).

The Danish Energy Association played an important part in creating this new and significant role for heat pumps in the energy system. In the background report to their annual meeting in 2009, they suggested heat pumps and electric cars as 'new ways of utilising electricity' (Dansk Energi, 2009: 26), which was necessary if more wind energy was going to be integrated. With more wind in the system, new and intelligent ways of consuming the surplus electricity had to be invented. The increasing utilisation of wind energy suggested the 'electrification' of heating (heat pumps) and transport (electric cars) in order for the increasingly green national electricity production to be utilised (Nyborg & Røpke, 2011). Then, in 2010, just before the publication of the Climate Commission's report, the Energy Association published another report, 'Smart Grid in Denmark', where the term 'smart grid' was firmly established for the first time in relation to the transition of the energy system (Energinet.dk & Dansk Energi, 2010). In the smart grid, consumers were seen as 'resources' for the electricity system because automation and control technologies and appropriate economic incentives would enable and motivate them to provide 'flexibility' in the system. Here, heat pumps were presented as excellent flexible agents, as the electricity companies could externally control their electricity consumption.

New regulation

During this period, several policy and regulatory measures, over and above the subsidy scheme of 2010/2011, were initiated as a means to help stimulate the dissemination of heat pumps. Already back in 2009, the decree on ground source heat pumps was changed so that heat pump pipes could be placed just 50 m from a water supply plant – a decision that had been supported by a report from the Environment Agency published in 2008, which concluded that there was no significant risk of ground water contamination from ground source heat pumps (Villumsen, 2008). Moreover, ever since the abolition of the test station, there had been no legal framework to ensure the efficiency of heat pumps, but in the new building regulations, BR10, which came into effect 1 January 2011, legal demands for the efficiency of heat pumps, as well as for gas and oil burners and ventilation systems, was introduced. Finally, in 2013, the tax on electricity was reduced by 42% for households that were registered as electrically heated and which consumed more than 4000 kWh per year.

Many new projects and knowledge building on dissemination

As a result of the energy agreement from February 2008, the new smart grid focus and the subsequent ambitious energy agreement from March 2012 led by a new Red-Green government elected in 2011, a range of projects concerning heat pumps was set in motion in the political system, the energy sector and at the universities. The first couple of projects were explicitly concerned with users and barriers in relation to investment in heat pumps. One of the main findings was that homeowners experienced poor service and suboptimal installations. Accordingly, the Energy Agency financed a big project that sought to address this issue (Energitjenesten et al., 2012). These studies were followed by an interest in the heat pump's 'smart grid potential' and, relatedly, the energy agreement from 2012 entailed the complete phasing out of individual oil burners, which had spurred an interest in exploring, for instance, 'alternative business models' for selling heat pumps in area 4 (see also Maagensen & Krøjgaard, 2013). One suggestion, for example, has been to let district heating companies invest in the heat pump so that the customer is merely paying for the heat. This focus was, among other things, also a result of the growing debate over the problems some homeowners had with getting a loan. Increasingly, pellet burners were also being discussed as an alternative to oil burners (Dansk Energi et al., 2013; Ea Energianalyse, 2012).

Discussion – can Denmark still have a fairy tale?

In light of the above account, it becomes clear that there are several reasons why Denmark missed an opportunity: The subsidy law and the work of the test station meant that up until 2001, 'the quality and effectiveness of heat pumps improved so much that the Danish heat pump manufacturers were at the absolute forefront in the field of individual heat pump systems' (Aagaard, 2003: 9; see also Beuse et al., 2000). Thus, 'many of the Danish produced heat pumps matched many of the products from the big international corporations when they were being tested at the TI up through the 1980s and the 1990s' (Poulsen, 2011: 50). Also internationally, the Danish heat pump industry was 'renowned for being at the highest technological level in the European market' (Aagaard & Bünger, 1997: 30). For instance, this was confirmed in 1997 when a ground source heat pump system produced by the Danish company Lodam Energy A/S won an international competition organised by the Dutch government. A lot of the success in terms of technological development was arguably due to a few 'fiery souls' in the heat pump field, such as Jørgen Gullev and Aagaard and the latter's strong commitment and management of the test station. In 2008, Aagaard was given an honorary award from the Danish refrigeration industry for his life-long work and engagement with improving energy efficiency and for raising the technological standards of refrigeration and heat pump technology (KuldeSkandinavia, 2008). Unfortunately, all the effort he put in during the 1980s and 1990s – and the many years of public investment in the test station – was 'wasted […] because the framework at the time made it impossible to sell heat pumps' (Poulsen, 2011: 50). Today, Danish heat pump manufacturers are loosing ground to an increasing number of imported brands. Only a few Danish manufactures are left and their export activities are estimated to be decreasing (Rambøll, 2011).

As shown in Figure 1, heat pumps quickly gained ground compared to wind power after the subsidy law came into effect in 1981, but 20 years later they had clearly lost the race.

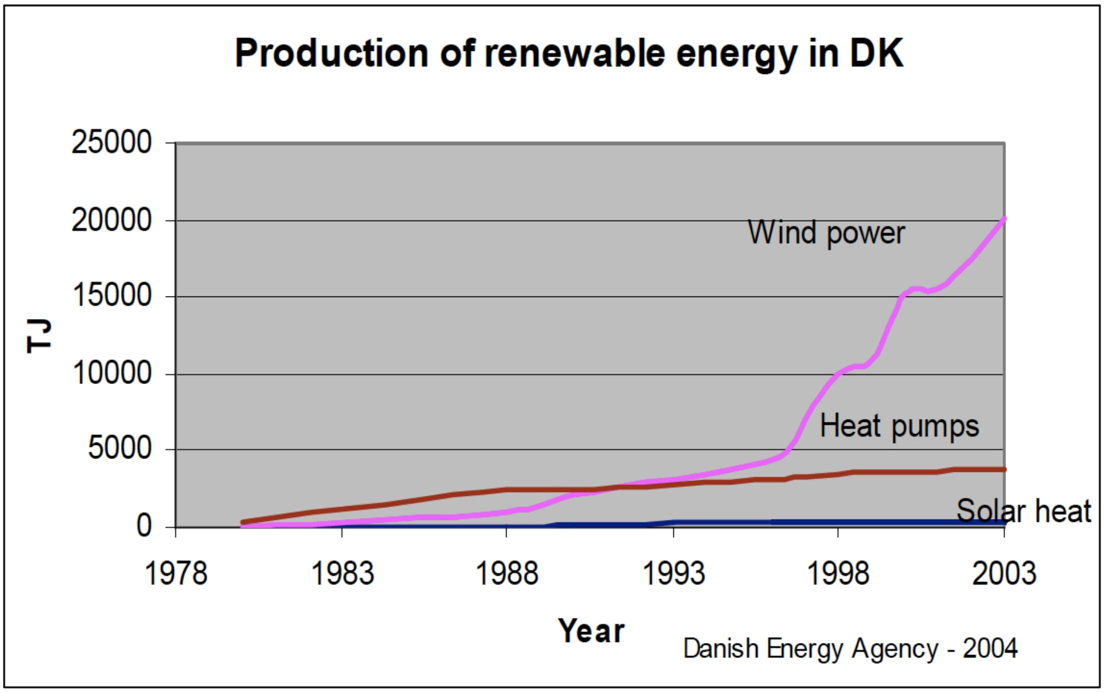

Figure 1: Production of renewable energy in DK. Source: Claus S. Poulsen

What happened in the mean time? Why was the opportunity not seized? The above actor-network based account of the development of heat pumps in Denmark and the discussion next provides some of the answers to these questions. In what follows, four elements that all seem to have played an influential role in the unfolding narrative will be discussed: Policy & Regulation, Technology & Design, Users & Civil Society, and Meaning Ascriptions.

Policy & Regulation

It is quite obvious that Danish energy policy did not support the heat pump very much. Firstly, the dissemination of collective systems and, notably, the natural gas project became a barrier to the development of renewable (heating) energy technologies in general. And secondly, heat pumps were often disfavoured compared to the other renewable technologies; for instance, they got a lower subsidy rate when the other renewable technologies' subsidies were raised, they were exempted from subsidies in collective supply areas when other renewables were not, and at other times they got no subsidies at all as a result of not being acknowledged as a renewable technology. Even though it was just the subsidy for 'electrically powered' heat pumps that was rescinded, heat pumps that were powered by other fuels were far from being as effective and were not on the Danish market. Moreover, energy taxes did not favour heat pumps either.

In Denmark, the decision to support collective supply systems, i.e. natural gas and district heating, is very sensible, as the country is small and the population rather dense compared to countries such as Norway, Sweden and Finland, where individual heating solutions – such as heat pumps – are more obvious in a techno-economical sense. However, as mentioned in the above historical account, the degree to which the natural gas project was managed sensibly (and fairly) is debatable. The technological and economic misjudgements that were made in relation to the planning and initial development of the natural gas net meant that it 'got a bad start' and quickly gained a lot of debt. This prompted the investors to expand the network to more sparsely-populated areas so gas could be used in individual boilers, which accordingly ousted other renewable alternatives that would have perhaps made more sense in those areas (Meyer, 2000). Moreover, the marketing methods the natural gas companies used to displace heat pumps were seemingly not always 'fair' to the heat pump manufacturers. However, as Jann Sjursen emphasised, the government did have an interest in spreading collective supply and securing the investment in collective systems. Nevertheless, the costly expansion of natural gas and the subsequent diminishing of the areas outside collective supply obviously curtailed the market for heat pumps. The heat pump manufacturers knew, however, very early on that they were not seen as competition to collective supply systems and therefore argued for dissemination in areas *outside* collective supply systems. Such a policy and action program was not supported either, though, because, among other things, the high taxation on electricity (also for heating) meant that it was comparatively more expensive to be a 'heat pump owner' than it was to have another renewable heating installation. The political decision to subsidise the conversion of electric heating with central heating plumbing – which was actually supported by the TI – instead of supporting air-air heat pumps, for instance, could have been considered more thoroughly, as Ejlif Nielsen, technical manager in the energy company EASV, argued. Installing central heating plumbing in a house is both rather extensive and expensive and the abovementioned regulation increased the risk that the conversion led to the installation of an oil burner instead. Arguably, if a large investment had just been made in a central heating system, an oil burner was a more obvious choice than the more expensive heat pump.

Finally, the cancellation of the subsidy law in 2001 and the disruption of the network and technological competence that had been built up by Aagaard over 23 years – just as Danish heat pumps were winning international prizes – probably also had an influence on how the market looks today. Although, the TI continues to have one of the best test facilities and laboratories for heat pumps in the world. Given that the subsidy scheme was removed, there was no longer the same 'legal' quality control and framework that supported heat pump efficacy and competent installers, and a range of possibly 'low quality' heat pumps and unauthorised installations could penetrate the market – thus the experiences with bad installations could start all over again.

Technology & Design

The very specific and complex technological design of the heat pump has also presented challenges to its dissemination. Whereas an oil burner is a simple technology that builds mostly on mechanical technologies, a heat pump is more complex. Hence, the installation of it requires much more ‘precise’ dimensioning than an oil burner and implies the meeting of several different craft traditions and skills, for example, plumbers/HVAC’s, electricians, cooling technicians and well drillers; all of which demands much tighter ‘project coordination’ and entails a higher risk that the installation may fail and the different groups can disclaim their responsibility of the quality. As the story has demonstrated, a significant source of the ‘bad reputation’ that heat pumps have gotten over time is due to poorly-installed heat pumps. The ‘complexity’ of the heat pump technology is also reflected in the fact that it has always struggled to be defined as ‘a renewable energy’ and struggled to ‘make sense’. Some sources of confusion have been, for instance, whether the heat pump gets its energy from the sun or the earth’s core; how its tubes could produce enough heat for an entire house given that they are buried in the (fairly) cold soil; and why it can be considered a renewable energy technology.

Furthermore, its complex technical design means that it imposes and depends on a wider network of other important actors or entities over and above the installers; for example, the ground water, water utilities, environmental groups, and so on. It also depends on the ‘good will’ of the much larger chemical and refrigeration industries, for whom the heat pump represents an almost ‘insignificant’ fraction of customers. Even though all these actors may have different agendas, they have all played an important role in the heat pump’s development in Denmark.

Finally, as with other technologies, the narrative demonstrates the importance of user-producer interaction and the value of having a domestic market when developing a technology (Lundvall, 1988). This was vital also in relation to the development of wind turbines. As Aagaard and other actors have argued several times, the diminishing domestic market made it difficult for the Danish manufacturers to continue their market leader position in Europe.

Users & Civil society

The lack of support from the grass-roots movement and the energy offices had an important part to play in the success of heat pumps. These actor groups were powerful and their activities acted as a barrier to heat pump dissemination, for example, by contributing to the formation of political opinion and by being critical towards heat pumps when householders sought advice from the energy offices. The energy offices’ resistance was persistent and, in the heat pump proponent’s view, not based on ‘facts’ but on ideology and an inherent opposition towards electricity companies. As late as 2001, Hans B. Jespersen, who was an energy consultant at the energy office in the Viborg area in Denmark, wrote an article in which he stated that ‘the total energy consumption [in Denmark] is increasing slightly and there are several explanations for this. One explanation is heat pumps’ (Jespersen, 2001: 5). In the article, Jespersen criticised heat pump advertisements distributed by a utility company on the basis that they did not illuminate how extra components such as air-conditioning and air-recirculation features would increase consumption. This led him to state that: ‘You sit back with the feeling that the main purpose of this marketing of heat pumps is to increase electricity consumption…’. Indeed, other means of obtaining pleasant indoor comfort could be acquired through, for example, solar shading and better insulation, which would probably result in less electricity consumption. However, in response to the above article, Jørgen Gullev claimed that the heat pump was ‘a highly appropriate and energy efficient replacement for electric radiators’, which does not give rise to increased consumption if used properly. According to him, what seemed like one of the biggest barriers was that ‘unfortunately, the energy consultants can be very simplistic in their evaluation of the benefits of using for example heat pumps’ and that the energy offices were just not ‘geared to accept that in many respects, both for the customer and generally for the environment, there can be a good and energy-efficient solution based on electricity' (Gullev, 2001: 20).

The story about OVE and the controversy over whether a 'solution based on electricity' is 'good' or not, as exemplified above, also signifies how *the meaning* of a technology varies greatly across actors and according to the system it is seen in relation to. In what follows, the variety of meanings ascribed to heat pumps and the implications for their development in Denmark will be discussed.

Meanings

For a long time, STS literature has argued that the 'truth' about a given technology is by no means a simple question, but rather depends upon its relation to other things. As the story about the heat pump's fight to be defined as a renewable energy and its later 'smart grid transformation' demonstrates, the truth about or meaningfulness of heat pumps was highly contested and contingent on how they were framed. In other words, how they were framed in relation to, for instance, the historically 'black' electricity system, to their utilisation of solar heating, to their threat to the gas project, or recently to wind energy and their benefits for the smart grid.

The historically negative framing of heat pumps by, for example, OVE was not only related to the fact that it was often the powerful electricity companies who promoted them, but also to what the electricity system looked like back then and how the heat pump was imagined to interact with it. Firstly, in the 1970s and 1980s, electricity production was almost exclusively based on fossil fuels and there was no way that OVE or other opponents at the time could foresee the 'green turn' it was going to take. Thus, in their view, the heat pump implied increased electricity consumption due to the interests of the fossil fuel based electricity companies, who had their own view on what a heat pump implied and what was 'best' for the customers and the system. Already back in 1974 at an international marketing conference for European electricity utilities – a time when heat pumps were being hyped as 'the next big thing' – Jørgen Gullev warned that specifically air-source heat pumps would need supplementary direct electric heating during the few periods of very cold weather. This would present a poor yearly load factor and perhaps result in special tariffs being occasionally imposed on the customer, thus making the efficiency of the heat pump unacceptable to the client. He therefore suggested that in order to give the buyer a good yield, 'it is of course essential that in addition to heating, the pump can be used as an air-conditioning unit during the summer' (Gullev, 1974: 3). Although this was a luxury that Gullev did not believe the Danes would ever embrace, such a comment points to the interests, concerns and focus of the electricity companies at the juncture when the heat pump was introduced in Denmark. The heat pump was an energy efficient technology 'in itself', which should be embraced, but it presented challenges to the system, and the solution to those challenges enabled a potential new practice that would possibly eliminate the energy efficiency gains obtained from converting to a heat pump.

Nevertheless, it seemed crucial for the dissemination of heat pumps that they could actually be defined as a renewable technology, and a few attempts at actually framing heat pumps in relation to 'solar heat' – instead of 'electricity' or 'electric heating' – were done by heat pump stakeholders early on. The sales director of the heat pump manufacturer Vølund A/S, H. Busch, for instance, wrote in an article in the VVS magazine from 1979: 'when one talks about solar heat, one normally talks about two different forms, namely 1) solar energy that is collected through solar panels, and 2) solar energy that is accumulated in the ground and collected by a heat pump installation via a tube in the ground' (Busch, 1979: 26). Later, and for a certain period, the Danish Energy Agency adopted the view that an electrically-driven heat pump was not a renewable energy installation because of the electricity needed for the compressor. Jørgen Gullev opposed this perspective: 'This argument is broadly equivalent to arguing that a solar panel, where the fluids in the solar collector circuit are transported via an electricity driven circulation pump, does not use renewable energy' (Gullev, 2007: 15). As written in the above historical account, in 1999 the AMHP, for instance, pointed out that heat pumps delivered twice the amount of renewable energy as the total amount of wind turbines in Denmark. Furthermore, and in that same year, Aagaard emphasised that, according to statistics from the Danish Energy Agency, heat pumps delivered approximately twelve times the amount of renewable energy as active solar heating facilities (Aagaard, 1999b). Yet it was their relation to electricity that dominated the meaning ascribed to them.

Persisting issues and challenges

What can be learned from the historical account and the above discussion? Firstly, what seems to be an important lesson from the history of the heat pump in Denmark is that we should learn from the past when we look towards the future. As Aagaard called for in 1999, 'first and foremost, we should avoid the repetitions and duplication, which regularly turns up, and instead exploit all the results and operational experiences that actually exist' (Aagaard, 1999a: 1).

Regarding the current attempt to disseminate heat pumps, it is interesting that most of the benefits, potentials, barriers and issues being discussed (and repeated) today have been pinpointed by Aagaard, Jørgen Gullev and others several times over the course of the heat pump's history. Concerning the potentials, from 1990 onwards, Aagaard and others in the heat pump network emphasised on several occasions that heat pumps could interoperate effectively with the growing share of wind energy. However, this role has only recently been deliberately adopted as a 'new idea' in relation to the smart grid. Moreover, 20 years ago Aagaard identified some of the challenges and issues that are now confronting heat pumps today when, back in 1994, he pinpointed problems associated with getting a loan for a heat pump due to the specific loan ceiling of each property. Furthermore, at the previously mentioned international conference for electricity utilities 40 years ago, Jørgen Gullev not only emphasised the currently much-debated issue of peak demand for heat pumps, but he also expressed a note of caution regarding the issue of hasty and thoughtless heat pump installation and poor guidance to customers. A particular heat pump problem, as formulated by Gullev (Gullev, 1974: 1), was their tendency to 'very easily be oversold' by 'some less serious working plumbers, electrical contractors and manufacturers' whose 'execution of heat pump installations […] may not in their final form satisfy the high expectations'. Thus, he saw a very important task for both installers, utilities, councillors and manufactures in procuring enough information about the heat pump in order to giver homeowners comprehensive advice about, for example, the suitability of a heat pump for their homes. If such sober information is not given, he argued, 'there is a risk that a number of installations with unsatisfactory working results may discredit the heat pump system in general' (Gullev, 1974: 2). Needless to say, this is exactly what happened in the 1980s and continues to take place today. As mentioned both at the beginning and again in the discussion above, the issues concerning poorly installed heat pumps are currently in the spotlight. If more attention had been paid to the experiences from the past, could some of the current installation problems and bad publicity of heat pumps have been avoided sooner?

Next we will initiate a discussion about the contemporary situation, including present issues and barriers, and then relate this to what we have learned from the past. Thus, we will consider whether barriers related to past themes are currently being addressed; what issues, controversies and 'non-relations' still exist; and, finally, where the potential lies. The four themes that comprised our analysis of past 'barriers' to the heat pump are also used as a heuristic to organise the discussion about the current situation.

The first section below not only covers some of the most significant current 'policy and regulatory' issues, but also covers how these issues are in many ways directly related to the characteristic and complex heat pump 'technology and design'. Accordingly, these themes will be discussed together below and followed by a discussion on the current issues related to 'meanings' as well as 'users and civil society'.

Policy & Regulation and Technology & Design

Lack of education

'There are many people who are put off as a result of getting poor guidance. […] He [the neighbour] got a ground source heating installation in an old house that was badly insulated, which he couldn't insulate more. And to get sufficient heating in the house he had to turn up the flow temperature just to get to 60° C and then efficiency falls […] the counselling today is way too bad' (interview with heat pump owner, 2011).

As indicated in the above quote, there continues to be instances of inadequate guidance and dimensioning due to the special demands that heat pump technology has. To address this situation, the Energy Agency has introduced a new voluntary 'Renewable Energy certification scheme' (RE Scheme), which came into effect on January 1st 2013. Accordingly, an installation company can use the title 'Renewable Energy Installation- or Montage Company' if certain educational requirements to install biomass ovens, PVs, solar heat and heat pumps are fulfilled.

However, according to the AMHP and other actors, there are several problems with this initiative. Firstly, the scheme comes on top of a range of (unregulated) green training programmes that have been offered to installers over the past few years. This seems like an inefficient strategy, as noted by energy consultant in the trade and employers association for craftsmen, Carsten Helmer, to the media: 'One scheme is replaced by another and what should you choose as an installer? As the market is at the moment, installers can virtually educate themselves from now on until they are retired without earning a dime' (L. Andersen, 2014a). Secondly, the RE scheme is considered a poorer alternative to the VPO scheme by the TI, who argues that there has not been a lack of educational offers over time, but rather a lack of regulation to secure that these educational offers are actually used. Thirdly, the Energy Agency has ignored suggestions from manufacturers and other stakeholders to make the scheme obligatory, and the installers are reluctant to take this expensive education if, for instance, political attention towards heat pumps disappears, which will not support demand. Moreover, only the boss of the installation company is required to have the certificate, while in principle any of the company's installers – such as trainees – are able to do the actual installation. The quality of the installation should be secured by the company's quality assurance system, but these systems are not always working in practice. An additional issue has been that the rhetoric coming from the Danish Energy Agency, the Danish Energy Association and others has, until recent years, been that one can 'just' exchange an oil burner for a heat pump, which may partly account for the poor installations. Lately, greater emphasis has been placed on improved communication to users or potential users about the heat pump's special requirements, perhaps because it was pinpointed in the Energy Agency's 2012 report on heat pump counselling. The report acknowledged that:

> ‘[T]he value of advising a homeowner to not chose a heat pump /prioritise other investments first can be just as big compared to bringing them closer to a heat pump since a bad investment or a wrong heat pump installation is very bad economically, both for society and the individual’ (Energitjenesten et al., 2012: 11)

Inconsistent policy

The lack of stability in terms of heat pump policy, for example, unfavourable taxation of energy and ‘half-hearted’, short-sighted or dispersed initiatives, which are evident in the historical account, is still a problem. This is due to the fact that policy volatility not only reduces the installer’s commitment to education, as mentioned above, but it also reduces the homeowner’s ‘investment willingness’. As Aagaard, for instance, pointed to in 1994, unstable and inconsistent policy means potential heat pump buyers do not know what direction the development will take and are uncertain whether they can secure sufficient operational savings in the future. The current, reduced electricity taxes are, for instance, only applicable until 2015, after which they are re-evaluated in accordance with the net price index. Finally, it is not only inconsistent energy taxes/prices that pose a problem, but also inconsistent state subsidy schemes, such as the last one in 2010/2011. Firstly, although the subsidy law obviously improved technological developments via, for example, the test station, subsidising the costs of heat pumps itself is perhaps a short-sighted means of reducing installation costs, as Ole Willumsen argued in 1986. Secondly, the sporadic subsidising of heat pumps possibly makes customers insecure about when they should invest in a heat pump, and some may wait with an investment in the hope that a new subsidy scheme will be presented at some point. The majority of our interviewees, for instance, bought their heat pump because of the latest subsidy scheme. As one of them notes concerning the on-going renovation of his family’s house: ‘As soon as there is a subsidy for something, we exchange it’ (see also Energistyrelsen, 2013). Thirdly, abrupt subsidy schemes can probably create sudden booms in demand, which the installers are not ‘ready for’.

Such dynamics may explain why the AMHP has often stated that the heat pump manufacturers are not interested in state subsidies and perhaps the heat pump industry would indeed have been better off if there had been no subsidy scheme in the first place. Besides the negative effects of inconsistent subsidisation – which was also a problem in the 1980s – it could also be argued that the ‘uneven’ subsidisation of different renewable technologies has created ‘unfair competition’. This is even more likely because the energy offices, which were not exactly promoting heat pumps, were the ones informing and guiding subsidy law. Yet, this does not constitute a call for arguments against state intervention in general; as has been demonstrated many times, leaving technological development to market forces alone does not necessarily promote a sustainable or otherwise desired development in society. Instead, and as pleaded for by Aagaard in his contribution to the Energy Environment Council’s competition, what this discussion suggests is that it is rather a question of planning energy policy and state intervention in a more ‘holistic and long-term’ fashion than has otherwise been the case for heat pumps in Denmark.

Building regulation and complex technology

According to the installer’s organisation, Tekniq, last year’s bad publicity and high rate of poor installations were, among other things, caused by a combination of an unexpected ‘boom’ resulting from the subsidy scheme of 2010/2011, and an unusually cold winter in 2013. More importantly, however, it was due to the fact that the building regulations are unsuitable for the heat pump’s ‘technological setup’. According to such building regulations, a heating system should be dimensioned to secure an indoor temperature of 20 degrees centigrade with an outdoor temperature of minus seven degrees centigrade. Installers routinely follow this regulation. However, in reality most people require a higher temperature inside, which renders the heat pump incapable of living up to the promised savings. Oil burners, on the other hand, while also dimensioned to provide a temperature of 20 degrees centigrade, do not need to be dimensioned nearly as 'precisely', and their considerably higher flow of temperature means it is much easier to turn up the heat without experiencing efficiency losses. Therefore, the installers need to be more attentive to this phenomenon and inform people more thoroughly about the expected savings in relation to the indoor temperature. Secondly, building regulations also require temperature control via thermostats in each individual room, which does not always interoperate optimally with the heat pump's own temperature control. Many homeowners express difficulties in 'calibrating' the heat pump to suit their houses' existing heat emitter system and thermostats. Often, the systems within a house are 'sub-optimised' individually, i.e. the different craftsmen optimise 'their' system, for example, ventilation vs. heat emitters vs. heat pumps and so on, respectively. This problem has yet to be solved because no actors have seen any business opportunities in doing it. However, more intelligent control systems are being developed that connect heat pumps more effectively both to the house and also to take outdoor weather conditions into consideration. Nevertheless, these systems have not yet sufficiently considered the fact that members of a household tend to open and close doors, windows, cook, and so on. In any case, these issues are also more relevant in a smart grid context and are not a general barrier to dissemination. As one manufacturer suggested, a simpler solution is that houses without any thermostats on heat emitters would actually be more suited to heat pumps. However, Danfoss – a leading manufacturer of thermostats – is lobbying for individual room temperature control to be included in building regulations. Nevertheless, building regulations and the demand for individual room temperature control is associated with greater difficulty in installing air-air and exhaust air heat pumps in new buildings in Denmark.

Unfavourable energy policy and messy market

Finally, there are still some regulatory and taxation system issues that favour other forms of heating over heat pumps. In comparison to district heating, for instance, the heat pump installer is still required to apply for permission from the municipality to install tubes in the ground. This is, nevertheless, unnecessary for an installer of district heating even though the district heating water also contains various additives – this is, however, an issue that is debated less frequently. Essentially, the energy taxation system still favours biomass, for example pellet burners, over electricity when it comes to heating. In one actor's view, the taxation system should rather make sure one kilowatt costs the same across all different renewable solutions – or at least that the different forms of heating are taxed according to how much they pollute. The 'truth' regarding this, however, is obviously also a controversial issue.

The market could also be regulated better. During the past five to 10 years, many different heat pump products of questionable quality – notably air-air heat pumps from abroad – have become available on the market, which was accordingly termed 'a true Klondike' a few years back. However, in 2011 the situation improved somewhat after the Energy Agency raised the demands for the proper energy efficiency labelling of air-air heat pumps according to EU regulations and when the energy efficiency demands for heat pumps in BR10 came into effect in 2011. Over the past few years, there has not been an Energy Agency comprehensive 'positive list' regarding heat pumps to guide consumers, since the one that existed alongside the last subsidy scheme from 2010/2011 disappeared. However, the Energy Agency has recently compiled a new 'heat pump list', which, as of 1 April 2014, requires all heat pumps – including all listed air-air, air-water and ground source heat pumps – to be tested by a third party. It is only by adhering to certain standards that manufacturers can get their heat pumps on the list. In addition, only those heat pumps on the list are eligible to receive subsidies from energy companies as part of their obligation to ensure energy-savings for households – a prerequisite decided on in the 2012 energy agreement. It is, however, voluntary to join the list. Nevertheless, the effect of the policy measures, such as the heat pump energy efficiency requirements in the BR10 or the RE scheme may be limited. Firstly, there is no control system in place to ensure that these energy efficiency demands are met when the municipalities handle building cases. Secondly, it is still possible to market and sell heat pumps that do not abide by certain energy efficiency requirements even though, in principle, it is illegal to install them (Jensen, 2012). Finally, both green education and third party testing is, as previously mentioned, voluntary in principle.

The new, third party regulation has been controversial since the Energy companies' newly-established heat pump association, Debra, is not supporting it. The AMHP, on the other hand, supports third party testing and has always been very insistent on quality from their members in terms of technological efficacy. They have also consistently emphasised the importance of skilful installations and have, for instance, worked together with TI to establish the 1994 VPO scheme. The problem with installations is not only an issue in Denmark, but was in fact mentioned in a recent international report requested by the Energy Agency (Sugden, 2013). The AMHP has used the report as an opportunity to invite the new Climate and Energy minister, Rasmus Helveg Petersen, to a strategy meeting to discuss these issues, including the controversies about the large variety of new green educational offers to installers. Likewise, the installer's organisation, Tekniq, is increasingly focusing on heat pumps and recently, autumn 2014, held a large meeting for all their members to discuss the current situation. Moreover, in September 2014, four well-attended seminars were organised for installers across the country. These seminars focused on the potential of heat pumps for the Danish market. Building such relations is important, as the heat pump installation market in Denmark is still 'young' and inexperienced and still rehearsing new configurations. Part of the reason why heat pump installations are comparatively more expensive in Denmark than in Sweden, for instance, is that Danish installers/entrepreneurs are less efficient in both their project handling and also the 'subcontracting' of the different tasks involved (electricians, plumbers, carpenters, etc.).

Users & Civil society

Perhaps the emerging attempts to build a stronger heat pump network is also reflected in the fact that, according to the Danish Energy Association's survey from 2010 (Epinion, 2010), the majority of Danes are familiar with a heat pump as opposed to the 'scarily low' number that was mentioned in the ELFOR market analysis in 1996 – and the 2010 survey was even conducted before the Energy Agency's new and stronger focus on heat pumps. The Energy Agency has, for instance, developed a 'consumer website' dedicated to energy saving solutions for the home, including a themed website on heat pumps with clear advice, such as a list of the most efficient heat pump products. However, this 'better information' does not imply that heat pumps are now automatically disseminated or interacting effectively with established systems, rules, expectations of comfort and practices; there are of course still differing interests at play among actors, as indicated above.

The lessons learned from the activities of OVE and the other civil society groups also demonstrates a more general point about the role of users in the transition of the energy system, a stance which the present eFlex (Nyborg & Røpke, 2013; Nyborg, in progress) and DREAM (Svanborg & Aarup, 2014) projects have also supported. Users do not necessarily fit into the passive 'consumer role' so often assigned to them by system designers such as politicians or actors in the energy system; nor can they be understood as one coherent or homogenous group with anticipated and simple, compliant 'action programs'. Clearly, the success of wind power in Denmark today is due to the innovative capacity of some active users, who had different visions, meanings and competences than the macro-actors, and who succeeded in building a stable alternative macro-network. Moreover, just as these past civil society groups were unwilling to enrol in the electricity companies' and government's nuclear power program, in which they viewed heat pumps as being a part, not all homeowners today are willing to be translated by the minister and become enrolled in the smart grid program by, for instance, investing in a heat pump. As discussed previously (Nyborg & Røpke, 2011), the ideas about who the users are, which is inscribed in new smart grid systems, are often rather simple. Often they do not reflect the implications and potentials of institutional innovation in terms of, for example, ownership structures (Walker & Cass, 2007) or the homeowners' desire for a more active role in the system, and they do not consider the complexity of the existing infrastructure and its co-development with domestic practices (Nyborg, in progress). Clearly, these findings indicate that a 'one size fits all' design and rollout of heat pumps is challenged by the 'messiness' of real life and the multitude of interests, competences and rationales of homeowners, as well as the performativity of their social practices.

Meanings

Finally, we want to discuss the meaning ascribed to heat pumps in the current development of – and visions for – the smart grid, which has thus far been discussed as something that has strengthened the heat pump. However, there may be a risk in adhering too exclusively to one specific agenda or energy system pathway. In the same way as the energy offices and OVE resisted heat pumps because they could not foresee the huge amount of wind energy that would become part of the electricity system, likewise, it is impossible for us to foresee the explicit direction or pathway that the energy system will take in the future – and whether the 'electrification/smart grid pathway' will be realised in line with the imagined scale (Lunde et al., in progress). If the definition of the heat pump is so intimately linked to the energy system to which it is a part and to its perceived role within that system, then there is perhaps a danger in it being linked too firmly to the smart grid agenda and there being an overly narrow focus on the heat pump's ability to elicit 'flexible electricity consumption' from individual households. What is the competition, for instance, from individual pellet burners? Or from natural gas and district heating systems where heat pumps function only as a supplement? In fact, it is being increasingly debated whether flexible electricity consumption from households really presents any real flexibility advantage in 'the bigger picture', and some argue that the heat pump will play a dominant role as large units in district heating systems (Mathiesen et al., 2011). However, the heat pump *is* also currently being linked to broader discourses and systems. In relation to the oil burner phase-out agreement, the Energy Agency is, for example, currently investigating the potential of natural gas fuelled heat pumps – although, in comparison to heat pump/natural gas hybrid systems, which are already on the market in Denmark, such a solution is far from being marketed. In the case of the hybrid systems, the idea is that while the heat pump is generally fuelled by electricity, during rare peak events – e.g. during very cold weather – the house's central water system is heated by a gas burner. While such possible uses stretch the natural gas resources, as previously argued by Aagaard, hybrid systems are actually well suited to a smart grid context because the problem of electricity peak demand is significantly reduced. In the same project, the potentials of low temperature district heating/heat pump hybrids are also investigated. Therefore, there may be an 'alternative' and more 'hybrid' path for heat pumps than the one that has thus far dominated the Danish view of a heat pump replacing a house's entire heating system in one go.

Conclusions and perspectives

What can be taken from this discussion? What are the chances for a heat pump 'fairy tale'? In an ANT perspective, this would require that opposing programs of action are translated and that stable networks and relations are formed. Concerning policy and regulation, and as argued by minister Martin Lidegaard, the oil burner phase out agreement, the new RE scheme and the lower tax on electricity are important steps. However, what seems clear from both the historical account and the current situation is that 'inconsistent' and 'non-holistic' policy and regulation has – not surprisingly – been a definite barrier to the success of the heat pump. The network does not have time to grow strong if regulations and ideas constantly change. As Claus S. Poulsen from TI says, the dissemination of heat pumps is definitely possible; it just takes time. The question is whether politicians and other stakeholders have the patience to wait for it. However, the AMHP and the TI have been actively involved in the campaigns, policy-making and lobbyism of the last few years to remedy this and enrol important actors in their action program. Despite controversies over, for instance, new third party control, and fights in the wake of new alliance-making between, for example, installers, energy companies and manufacturers (see e.g. Danfoss Danmark, 2012; Wittrup, 2010), it seems that the heat pump's stakeholders are acquiring a stronger profile and have increasingly been working together to give the heat pump 'the position in energy plans and reports that it deserves', as Gullev has previously argued (1991). Nonetheless, ensuring a stable, long-term policy plan concerning subsidies and energy taxes would obviously be beneficial. In relation to subsidies, one suggestion is to subsidise the cost of insulation or improvement of the heat emitter system, for example, larger radiators, when people buy a heat pump instead of subsidising the cost of the heat pump itself. Concerning the 'investment barrier', interesting alternative models are being explored (EXERGI Partners et al., 2014; Maagensen & Krøjgaard, 2013). However, there are still regulatory issues and supportive systems surrounding the heat pump – such as building regulation – that can be scrutinised further.

Concerning technology and design, it seems that the heat pump's characteristic technological features are beginning to gain recognition in terms of the need for the further education of installers. However, perhaps a more hybrid approach is more effective than focusing entirely on heat pumps as a replacement for oil burners.

The lessons from the users is that many of them have different rationales to those expected, and some have a strong desire to interact with the system, but also that they draw on each other in 'investment' situations and like to share their experiences with the daily operation of the heat pump. This calls for using homeowners as a resource and for a more systematic exploration of the potentials of user involvement in the development of the heat pump and its interaction with other systems, as well as practices, in the home. In our experience better support systems *after* the acquisition of the heat pump are needed, for instance, through user-user interaction or peer-to-peer advice, where experiences with, for example, adjusting the pump to the house could be shared with other users. In relation to this, we would like to point to experiences with user-run Internet forums, which may support the ability of some of the most inventive users to 'provide top end technical assistance to other users that facilitate market creation of these technologies' (Hyysalo et al., 2013a: 46). In addition, a grass-roots level promotion programme has been suggested (Sugden, 2013) as well as 'open-homes' events, where experienced heat pump users – 'local experts' – open their homes to potential heat pump users (Heiskanen et al., in progress). As stated earlier, such events were also widespread in Denmark in the 1970s in relation to the development of sun, wind and biomass technologies. Therefore, in addition to the work done by the Energy Agency in developing a ‘case-bank’ with concrete examples of energy renovated homes, for instance, the conversion to heat pumps, more attention to the development of these types of platforms for users to interact, exchange experiences and to help each other in making their heat pumps work optimally could be beneficial.

Concerning the heat pump’s new meaning ascriptions, a strong ally has come in the form of the smart grid agenda, which is also part of the reason why strong networks are being built. However, as we have argued, we should remain open to the different potentials and implications of the heat pump in case the dominant vision is not realised.

Finally, we call for greater attention to the heat pump’s interaction with changing everyday life practices and to the possible negative energy implications. This issue was only briefly discussed in the paper and remains under-investigated. A Danish study of air-air heat pumps has, for instance, pointed to how heat pumps ‘potentially contribute to long-term changes in comfort behaviour and practices, which may undermine the energy saving potential’ (Christensen et al., 2011: 1963). Thus, considerations about whether heat pumps are an unconditionally sustainable solution and which issues require sensitivity if heat pumps are to be ‘a normal and unquestioned heating form’ in Denmark are also needed.

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13 Co-author statements

Co-author statement in connection with submission of PhD thesis

With reference to Ministerial Order no. 1039 of August 27 2013 regarding the PhD Degree § 12, article 4, statements from each author about the PhD student's part in the shared work must be included in case the thesis is based on already published or submitted papers.

Paper title: Energy impacts of the smart home – conflicting visions

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Scientific contribution of the PhD student (all participating PhD students) to the paper:

Sophie Nyborg developed the idea for the paper in collaboration with the co-author, but conducted the empirical fieldwork and analytical work her self. Sophie Nyborg wrote a draft version of the paper, and revised it according to the co-author's comments. Sophie Nyborg handled the communication with the editors of the proceedings and revised the document in accordance with review comments after discussions with the co-author.

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